DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DETERMINATION OF THE STRENGTH CHANGE IN ANDESITIC LAVAS OUTCROP IN İZMİR CITY CENTRE DEPENDING ON ANISOTROPY

by
Sungeni TEMBO

July, 2020
İZMİR

DETERMINATION OF THE STRENGTH CHANGE IN ANDESITIC LAVAS OUTCROP IN İZMİR CITY CENTRE DEPENDING ON ANISOTROPY

A Thesis submitted to the
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in Geological Engineering, Applied Geology Program

by
Sungeni TEMBO

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled "**DETERMINATION OF THE STRENGTH CHANGE IN ANDESITIC LAVAS OUTCROP IN İZMİR CITY CENTRE DEPENDING ON ANISOTROPY"** completed by **SUNGENI TEMBO** under supervision of **ASSOC. PROF. DR. CEM KINCAL** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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DETERMINATION OF THE STRENGTH CHANGE IN ANDESITIC LAVAS OUTCROP IN İZMİR CITY CENTRE DEPENDING ON ANISOTROPY

ABSTRACT

The northwestern part of the city of Izmir majorly lies on andesite lavas. The major formation features are basaltic, pink and grey andesite that are adversely prone to weathering. The andesite rocks of the region are characterized by self-organized directional cooling joints and flow bands features that entail possibilities of inherent anisotropy that pose a challenge to geotechnical design such as tunneling, excavation and construction. The study area has become evident with these projects, therefore investigating the properties of andesite type of rocks is now even more important. This study investigates the anisotropic characteristics of andesite lavas outcrop of Bornova the northern part of İzmir city (Turkey).

The study principally investigates the influence of anisotropy on pink and grey andesite rock strength in other words strength anisotropy. A detailed anisotropy analysis was conducted by field work study and laboratory tests. Field work included geological mapping and sample collection. To evaluate the changes in rock strength depending on the direction, in the laboratory fresh intact block samples of pink and grey andesite were cored at 0°, 30°,45°,60°and 90° angles in respective to the lava flow direction. Firstly, the samples were subsequently subjected to microscopical analysis, whole rock geochemistry analysis, X-ray diffractometer studies, porosity and unit weight tests, ultrasonic p-wave velocity tests (Vp), Uniaxial Compressive Strength (UCS) test, Brazilian Tensile Strength (BTS), Point Load Index (I_{50}) tests and Bohme abrasive resistance test.

The major findings of the study in relation to anisotropy dependence indicated that the rock's strength is maximum when the anisotropy angles is close to 0° and 90° while minimum between 30° and 45° respectively in both rocks further classifying the anisotropy exhibited as "weak anisotropy" after UCS, BTS, I_{50} and Vp anisotropy quantification indices results. The rock's UCS in grey andesite was classified as "high strength” and pink andesite “high-medium strength”. Primarily other factors that may negatively influence the performance of andesite were also investigated. The samples were exposed to corrosive environments under accelerated weathering physical and chemical, thus wetting-drying and freezing-thawing, sodium sulphate and magnesium sulphate soundness tests.

Finally, the quality and durability of the rock was evaluated by using rock quality indicators i.e. saturation coefficient, wet to dry strength ratio and Static Rock Durability Index (RDIs). These quality indicators classified the quality and durability of the rock as “good”.

Keywords: Material properties, strength anisotropy, andesite, RDIs

İZMİR ŞEHİR MERKEZİNDE YÜZEYLEYEN ANDEZİT LAVLARININ DAYANIMLARININ ANİZOTROPİYE BAĞLI DEĞİŞİMLERİNİN BELİRLENMESİ

ÖZ

İzmir şehrinin kuzeybatı kesimleri genellikle andezitik lavlar üzerine oturur. Başlıca formasyon özellikleri, kolaylıkla ayrışabilir bazik pembe ve gri andezitlerdir. Bölgedeki andezitik kayaçlar, tünelcilik, kazı ve inşaat gibi jeoteknik dizaynlarda güçlükler oluşturan kayacın oluşumuyla meydana gelen anizotropi özelliği gösteren, akma bandları ve soğuma çatlaklarıyla karakteristiktir. Çalışma alanı bu projelerle ön plana çıkmıştır. Bu nedenle anzidezit türü kayaçların özelliklerinin incelenmesi önem kazanmıştır. Bu çalışma Izmir (Türkiye) şehrinin kuzeyindeki Bornova'da yüzlek veren andezit lavının anizotropi karakteristiklerini araştırır.

Bu çalışma, pembe ve gri andezitlerin dayanım anizotropisini inceler. Detaylı anizotropi incelemesi arazi çalışmaları ve laboratuvar deneyleriyle gerçekleştirilmiştir. Arazi çalışması jeolojik haritalama ve örnek toplamayı içerir. Kayaç dayanımındaki yöne bağlı değişimleri belirlemek için, akma bandı konumları dikkate alınarak, pembe ve gri andezit blok örneklerinden 0°, 30°,45°,60°ve 90° dereceler için laboratuvar ortamında karotlar alınmıştır. İlk olarak, örnekler üzerine mikroskobik analiz, tüm kayaç jeokimyasal analizi, X-ışını difraktometre analizi, porozite ve bitim hacim ağırlık testleri, ultrasonik P-dalga hızı testi (Vp), Tek Eksenli Basınç Deneyi (UCS), Brazilian İndirekt Çekme Gerilmesi (BTS), Nokta Yükleme Indeksi Deneyi (Is_{50}) ve Bohme aşındırma dayanım testleri yapılmıştır.

Bu çalışmanın anizotropiye bağlı başlıca bulguları göstermiştir ki, anizotropi açıları 0° ve 90°ye yaklaştıkça kayaç dayanımı maksimum, 30° ve 45° aralığında minimum değerler almış, heriki kayaç grubu da daha sonra Tek Eksenli Basınç, Brazilian İndirekt Çekme Dayanımı, I_{50} and Vp anizotropi ölçme indis sonuçları değerlendirildiğinde anizotropiye göre "zayıf anizotropi" göstermiştir. Gri andezitler tek eksenli basınç dayanımları dikkate alındığında "yüksek dayanımlı" ve pembe andezitler "yüksek-orta dayanımlı" olarak sınıflanmıştır. Andezitin performansını

negative etkileyen başlıca diğer faktörler ayrıca araştırılmıştır. Örnekler fiziksel ve kimyasal hızlandırılmış ayrışma deneyleri altında korozif koşullara maruz bırakılmıştır. Bu deneyler ıslanma-kuruma, donma-çözülme, sodium sülfat ve magnezyum sülfat deneyleridir.

Sonuç olarak, kayaçların kaliteleri ve durabiliteleri doygunluk bağıntısı, ıslak/kuru dayanım oranı ve Statik Kaya Durabilite İndeksi gibi kaya kalite belirteçleri kullanılarak değerlendirilmiştir. Çalışılan kayacın kalitesi ve durabilitesi kullılan kalite belirteçlerine göre "iyi" olarak sınıflandırılmıştır.

Anahtar Kelimeler: Malzeme özellikleri, dayanım anizotropisi, andezit, RDI

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CHAPTER ONE
INTRODUCTION

1.1 Introduction

This study was conducted as Master of Science thesis fulfilment requirement neccessary for the award of a Master of Science Degree in Applied Geology by the Graduate school of Natural and Applied Sciences, Dokuz Eylül University, Turkey.

1.2 Study Area

The study area in Figure 1.1 is a residential area in Laka neighbourhood located 4km away from the centre of Bornova district and stands at an altitude of 150m, in the north western part İzmir city, Turkey.

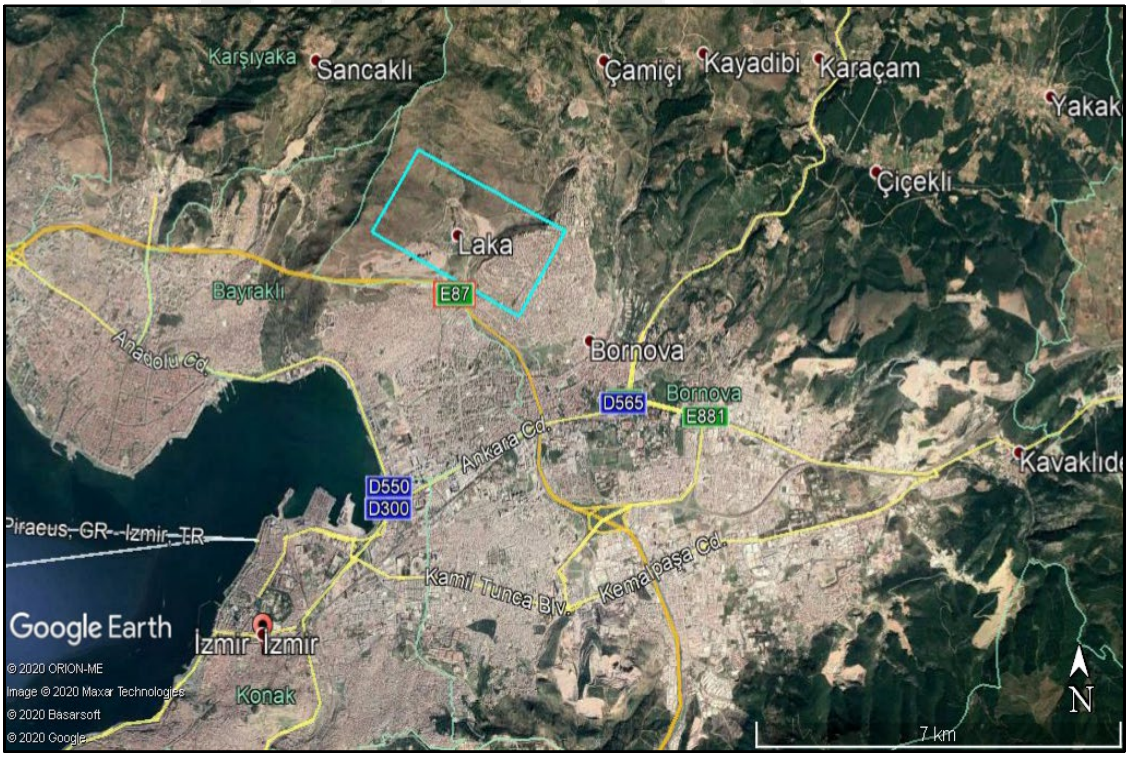


Figure 1.1 Location map of the study area (Google Earth, 2020)

1.3 Aim of study

The main geological formation of the study area is andesite lavas outcrop. Andesite lavas are mainly characterized by joints and flow band formation. These features provoke inherent anisotropy characteristics that influence its performance as a building material. In the recent years, the study area has seen an enormous increase in infrastructure construction such as residential housing, tunnels etc. Therefore, the physical and mechanical properties are critical to evaluate the performance of the rock.

The aim of the thesis research is to investigate the influence of anisotropy.The study investigates the evidence of anisotropy depicted in laboratory studies of the rock i.e. the rock's strength is closely monitored in function of the anisotropy plane orientation. The second objective is to quantify the observed anisotropy. Lastly the research also investigates other parameters that may influence the changes of rock strength and its overall performance.

1.4 Method of study

The influence of anisotropy on rock strength study was conducted on laboratory test analysis basis:

In the first stage of the study a general field investigation was conducted in the study area which habours pink and grey andesite.

In the second scope of the study, intact block samples of pink and grey andesite were randomly collected from the study area. Subsequently andesite samples were prepared taking into consideration the anisotropy orientation and respective test specification. Tests conducted on the samples include petrographic microscopic analysis on thin sections, chemical analysis: X-Ray Diffractometer (XRD) analysis and bulk analysis via Induction Couple Plasma Mass Spectroscopy (ICP-MS), physical property tests, mechanical property tests and accelerated weathering tests.

The physico-mechanical property tests evaluated include unit weight, porosity, P-wave velocity, water absorption, compressive strength, point load index and Brazilian tensile strength. The accelerated weathering tests performed are wetting-drying, freezing-thawing, Magnesium Sulphate (MgSO4) and Sodium Sulphate (Na_2SO_4) salt crystallization. The existing relations between the parameters obtained were established and compared.

In the third scope of the study, rock samples were subjected to uniaxial compressive strength, point load index, Brazilian tensile strength test and P-wave velocity,taking into importance the physical state and anisotropy orientation. The changes of strength revealed by the parameters between anisotropy angle 0° and 90° were tabulated. The anisotropy exhibited was classified and quantified by using the anisotropy indices from their parameters.

In the fourth scope of the study, the accelerated weathering tests were applied on the rock samples which include physical weathering; wetting-drying and freezing-thawing sodium sulphate and magnesium sulphate salt crystallization tests. The mass loss at the end of every test cycle was tabulated and uniaxial compressive strength test was applied after the overall completion of the given tests.

Lastly evaluating the rock quality and sustainability by taking into consideration the saturated and dry uniaxial compression resistance ratio, saturated and dry Brazilian tensile strength ratio and saturated-dry point load strength index rate, saturation coefficient and static rock durability index were evaluated.

1.5 Literature review

1.5.1 The influence of anisotropy on rock mass

The strength of a rock is dependent on several factors that is mineral composition and rock type, rock grain size, rock weathering, rock density and porosity, rate of loading, confining stresses, geometry, size and shape of the test specimens, rock anisotropy, water pore pressure and saturation, testing apparatus, temperature, time (Paterson, 1978). Rock anisotropy is a distinct feature that is applied in mining, geo-environment, civil engineering etc., that is because the anisotropic nature of rock materials influence the physical and mechanical properties of a rock that vary with the orientation of the anisotropy plane. Anisotropy plays an important role in evaluating the stability of underground and surface excavations of rock mass. However, it is often underestimated in geotechnical analysis, that is due to the existing geotechnical developed design methods which adhere to isotropic rock mass than anisotropic rock mass. Extensive studies of rock mechanics and their behavior have suggested some rock materials are anisotropy due to the variation of parameters with direction. However, the exhibition of anisotropy in rock mass is not uniform that is solely due to the difference in origin of rock mass they are either sedimentary, metamorphic or igneous. The structures of the rocks that affect anisotropy are categorized as primary and secondary.

The primary structures also known as the micro-geological features are exhibited at different stages of rock formation. These rock formations include rock fabric, schistosity and texture. The features are related to the grain size and are found at a microscopic scale. Consequently, the anisotropic behavior of rock mass is dependent on the fabric and textures of the minerals constituted in the rock material. Anisotropic behaviors are greatly exhibited in sedimentary and metamorphic rocks due to the presence of sedimentation phenomenon resulting in to bedding planes in sedimentary rock and the foliation of phenomenon where the minerals lay flat/long resulting into banding in metamorphic rocks (Chen et al.,1998). Anisotropy is also exhibited in igneous rocks due to the laying of magma flow during the formation resulting into bands however, it is rare but should not be ignored.

The secondary features also called macro-features that influence anisotropy of rock mass are “discontinuities”. These discontinuities include: i) bedding planes, ii) cracks and fractures and (iii) shear planes and faults (Salager et al.,2013). The influence of these planes on anisotropy is quite significant. Thus, the planes limit the elastic behaviour of rock material, the planes act as weakness planes therefore, reduce the rock strength significantly and they also affect the scale i.e the modelling of the planes is either inferred or distinct (Bobet et al., 2009). A significant change on strength anisotropy due to single weakness plane have been introduced by (Jaeger & Cook, 2007). However, jointed rock mass also influences strength anisotropy by (Hoek & Brown, 1980) criterion which concludes that rocks with a single joint are perceived as highly anisotropic and those with three to five intersecting joints are perceived as isotropic. In addition, the strength of a jointed rock mass is dependent on the interlocking of rock mass.

Anisotropy is characterized and measured by the following parameters are considered permeability, stiffness, seismic and strength (Amadei, 1996). This study mainly focuses on the influence strength anisotropy has on andesite rock strength. Secondly it determines the degree of anisotropy. It further elaborates other factors i.e. the behavior of andesite rocks under corrosive environment and how it they influence its rock strength.

1.5.2 Strength Anisotropy

Jaeger & Cook (2007) suggested that even if the rocks do not contain any discontinuity plane, they may show anisotropic property depending on the properties gained during their formation. In order to define anisotropy, it is necessary to determine the change of rock strength according to the loading position angle. The angle between the loading and the planes of anisotropy orientation is defined as (β) (Figure 1.2).

Ramamurthy (1993) extensively a wide variety of intact rocks usually exhibit anisotropic behaviours in respective to their strength, deformation modulus and permeability parameters. However, intact igneous rocks tend to be isotropic than metamorphic and sedimentary rocks. Anisotropy is mainly influenced by the developmental features of a rock mass such as schistosity and bedding planes. The strength and deformational responses of anisotropic rocks is highly dependent on the strength obtained from weakness plane. These weakness planes are responsible for the anisotropic behaviour exhibited in a rock, whose origin is either from induced rock features i.e. schistosity and bedding planes or inherent rock features i.e. fractures, joints and faults. The strength of andesite in respective to anisotropy angle is dependent on magnitude of the principle stress and orientation of flow bands and cooling joints.

Strength anisotropy refers to the variability of strength of an intact rock indicated by uniaxial, biaxial and triaxial loading in function of the loading direction. Its degree of intensity is described by the degree of anisotropy (RC) which is defined as a ratio $\sigma_c(max)/\sigma_c(min)$, where $\sigma_c(max)$ is the maximum uniaxial compressive strength value the oriented sample usually perpendicular or parallel to the planes of anisotropy, and $\sigma_c(min)$ is the minimum value of σ_c obtained from oriented samples under uniaxial compression, usually occurring at the weakness plane of a rock mass. After an extensive investigation on the strength behaviours of rock mass by several authors, it is indicated that the maximum failure strength of rock occurs either at β= 90° or β = 0° whereas, the minimum strength occurs between 20° and 45° usually where the plane of weakness is existent. The figure below is a visual concept of strength anisotropy of a rock under compressive strength test, the two cylindrical anisotropic rock specimens shown in Figure 1.2a define the weakness planes making angle β with a major principal stress σ_1. The angle β indicates the orientation of the "inclination angle". The uniaxial compressive strength variation in Figure 1.2b unveils the pattern of anisotropy exhibited by variations of failure strengths in single and multiple plane specimens.

Considering uniaxial compressive strength test applied on a cylinder specimen with a single plane of weakness. Generally, the minimum strength is between angle (β) = 30°and 45°,and the maximum strength usually at 0° and 90°.

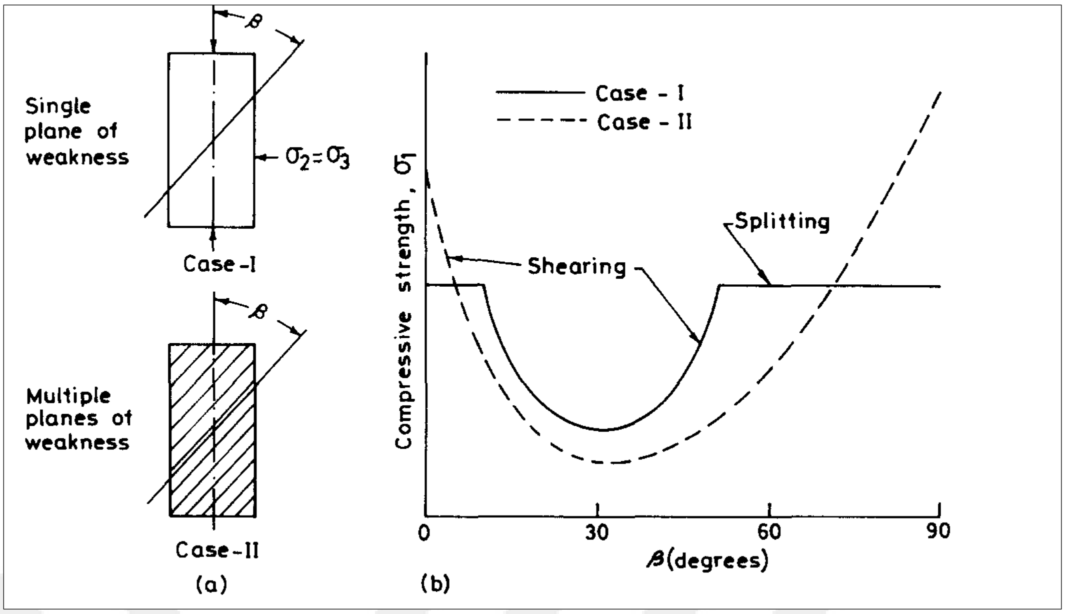


Figure 1.2 (a) type anisotropy samples showing a variation of features (b) compressive strength(σ_1) in function of angle orientation (β) curve pattern, from Ramamurthy *(1993)*

The anisotropy exhibited in a rock is quantified by the anisotropy index derived from parameters of interest. The systems extensively used to quantify the degree of anisotropy are the ultrasonic velocity anisotropy index (VA), compressive strength anisotropy index (Rc) and point load index (Ia).

Singh et al., (1989) proposed parameters to qualify and quantify the anisotropy exhibited by a rock. The concept of the "type of anisotropy" and "ratio anisotropy". Thus, the type of anisotropy is the qualification term used to denote the curve pattern of the variations of compressive strength in function to angle orientation, which is either "U-type" undulatory type or shoulder type. The "anisotropy ratio" is also known as the anisotropy index, is the max/min uniaxial compressive strength ratio. The maximum compressive strength in relation to anisotropy angle is observed at β = 0° and 90°, while the minimum compressive strength is observed at β between 30° and 45°, that defies the magnitude of anisotropy presented hence quantifying the anisotropy exhibited by the rock mass. Singh et al., (1989) further proposed a strength anisotropy classification grade of compressive strength anisotropy ranging between very high anisotropy to isotropic.

A research conducted on the estimation of strength anisotropy using point load test conducted by Broch (1983). Reveals that the strength anisotropy using point load test is quite easy and inexpensive compared to using uniaxial compressive test that is because the major principal strengths (minimum and maximum) are generally found at parallel and normal orientation whereas for compressive strength gives the same maximum strength value at two easily defined inclination and important thus the parallel to and the normal to the weakness plane.

Generally based on observations the minimum point load strength is exhibited when the loading is parallel to the foliations of a rock causing splitting along the plane of weakness (Saroglou & Tsiambaos, 2007). The strength anisotropy index ratio ($I_{50}a$) is calculated between the normal to and parallel to inclination ratio $I_{(50)\ max}/I_{(50)\ min.}$ The equation of anisotropy index proposed by ISRM (1985)point load strength suggests that there is a great relation between the degree of foliation and the point load index value. ISRM (1985), proposed a scheme to classify the degree of anisotropy in exhibited by point load index which is also similar to the one Tsidzi (1990) proposed for metamorphic rocks.

Tsidzi, (1997) proposed a classification of anisotropy in metamorphic rocks based on ultrasonic velocity. After a series of laboratory studies, the evident effect of foliation on the measurement direction (0°, 45°, 90°) is considerable. Tsidzi (1997) suggests that “strongly”, “moderately “and “weakly” foliated rocks are expected to demonstrate a degree of velocity anisotropies (VA) of 40-20%,20-6% and 6-2% respectively.

CHAPTER TWO
GEOLOGICAL DESCRIPTION OF STUDY AREA

Geology and block sample locations map of the study area in Figure 2.2 shows a simplified geology of the study area. The Bornova Melange, which overlies the basement rocks in the İzmir, underwent intense tectonic deformation during and after formation (Erdogan, 1990; Koca M. Y., 1995; Kincal, 2005; Kincal & Koca, 2009).The Upper Cretaceous-Palaeocene age Bornova Melange rocks, bearing a flysch matrix and different age and size limestone olistolithes in the matrix.

The flysch is composed of sandstone-laminated mudstone (shales) intercalations and conglomerate (Erdogan, 1990; Kincal, 2005). Shales are the dominant component of the matrix, and sandstones are found as lenses and interlayers between the shale layers.

The Bornova Melange is extremely folded and cracked by the tectonic regime of the region. Neogene age sedimentary rocks discordantly overlie the Bornova Melange rocks (Fig.2.1 and 2.2). These Neogene sedimentary rocks consist of conglomerate, sandstone, laminated marl and limestone from base to the top, respectively (Koca et al., 2000; Koca & Kincal, 2004).

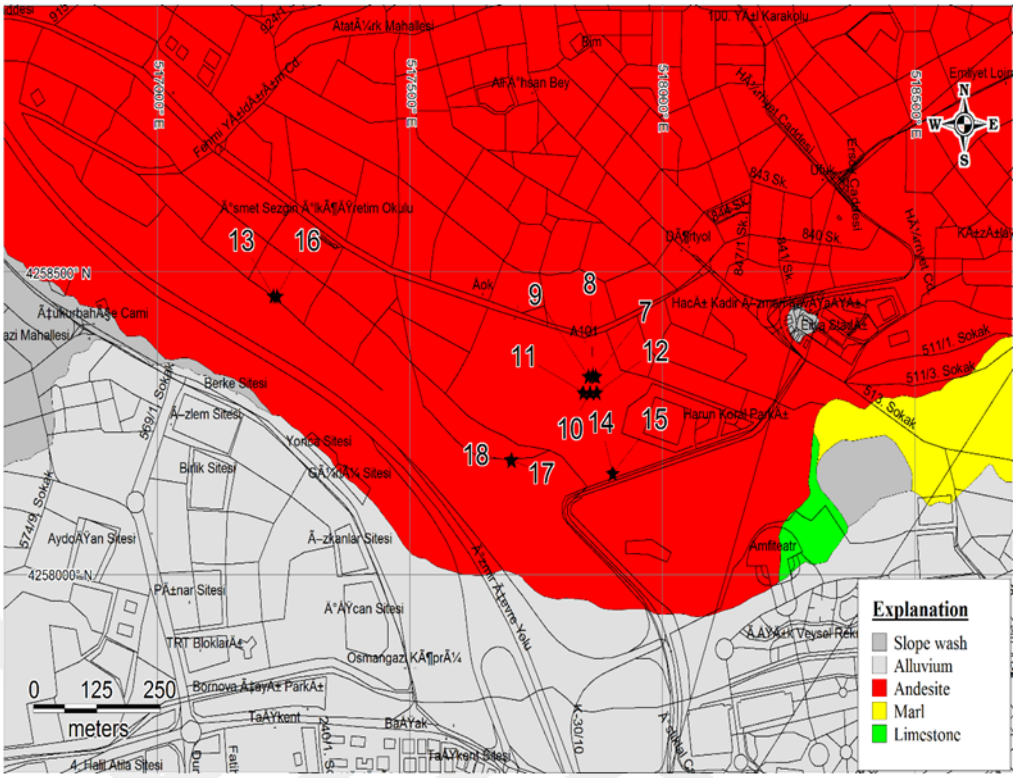


Figure 2.1 Geology and block sample locations map of study area *(Kincal, 2005)*

The Upper Miocene-Pliocene age volcanic rocks are widespread outcrop in and around the Izmir city centre and discordantly overlie all prementioned rock units (Figure 2.1 & 2.2). The volcanic rocks are dacitic tuff, dacitic lava, andesitic tuff, agglomerate and lava subunits (Kıncal et al.,2009). The volcanic sequence generally has tuffs at the base and is continued with agglomerate and andesitic lavas.

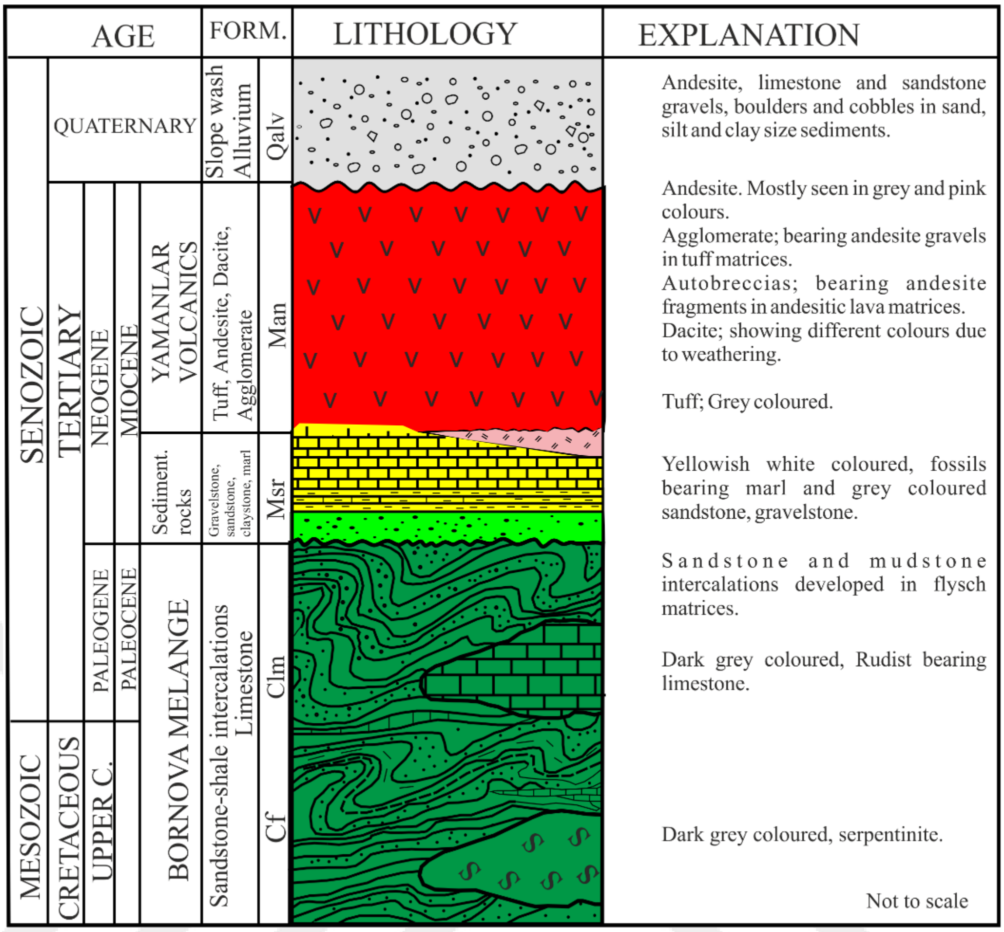


Figure 2.2.Stratigraphic columnar section study area *(Kincal, 2005)*

Quaternary age slope wash and alluvium unconformably overlie all geological units. Alluvium was formed by sediment transfers from surrounding rivers. Quaternary sediments with a maximum thickness of 300 m is observed in the southern part of the study area which named as Bornova Plain.

CHAPTER THREE
MINERALOGICAL, PETROGRAPHICAL AND GEOCHEMICAL STUDY

3.1 Mineralogy and petrography

The study of rock fabric is essential in rock mechanics to understand the influence of microstructures of physical and mechanical behaviour of a rock. The fabric is generally referring to the constituents of a rock matrix. The study rock fabric under a microscope, defines the orientation, lithological contact, fracture and inherent planes that adversely influence the behavior of a rock. The alignment of the minerals and the presence of fractures that may affect the mechanical properties of are important in distinguishing anisotropy. To initiate this analysis thin sections from uniaxial compressive test cores and fresh rock were prepared. The test was performed of thin-section obtained from fresh rock whose main objective was to distinguish the texture and mineral composition of the rock.. The grey and pink andesite thin sections were prepared and analysed using a polarizing microscope with a digital camera at the Geology engineering department (DEU).

3.1.1 Grey andesite

The thin sections of the Bornova grey andesite is composed of mainly of phenocrystal minerals plagioclase, pyroxene (clinopyroxene and orthopyroxene), amphibole and biotite. The plagioclase in zoned. The section presents a lot of parallel clinopyroxene and a few traces of 90° orthopyroxene. In addition, they also present traces of lamprobolite (basaltic hornblende) red-brownish in colour (Figure 3.3). The number of biotite and pyroxene minerals is equal. The samples indicated a hypocristalline texture whose matrix consists of dark glass and 90% of microlite. The matrix is rich mainly in feldspar plagioclase and other phenocrystals. The minerals of the specimens do not present any form of alteration and fractures.

Figure 3.1 Images of grey andesite (Personal archive,2019)

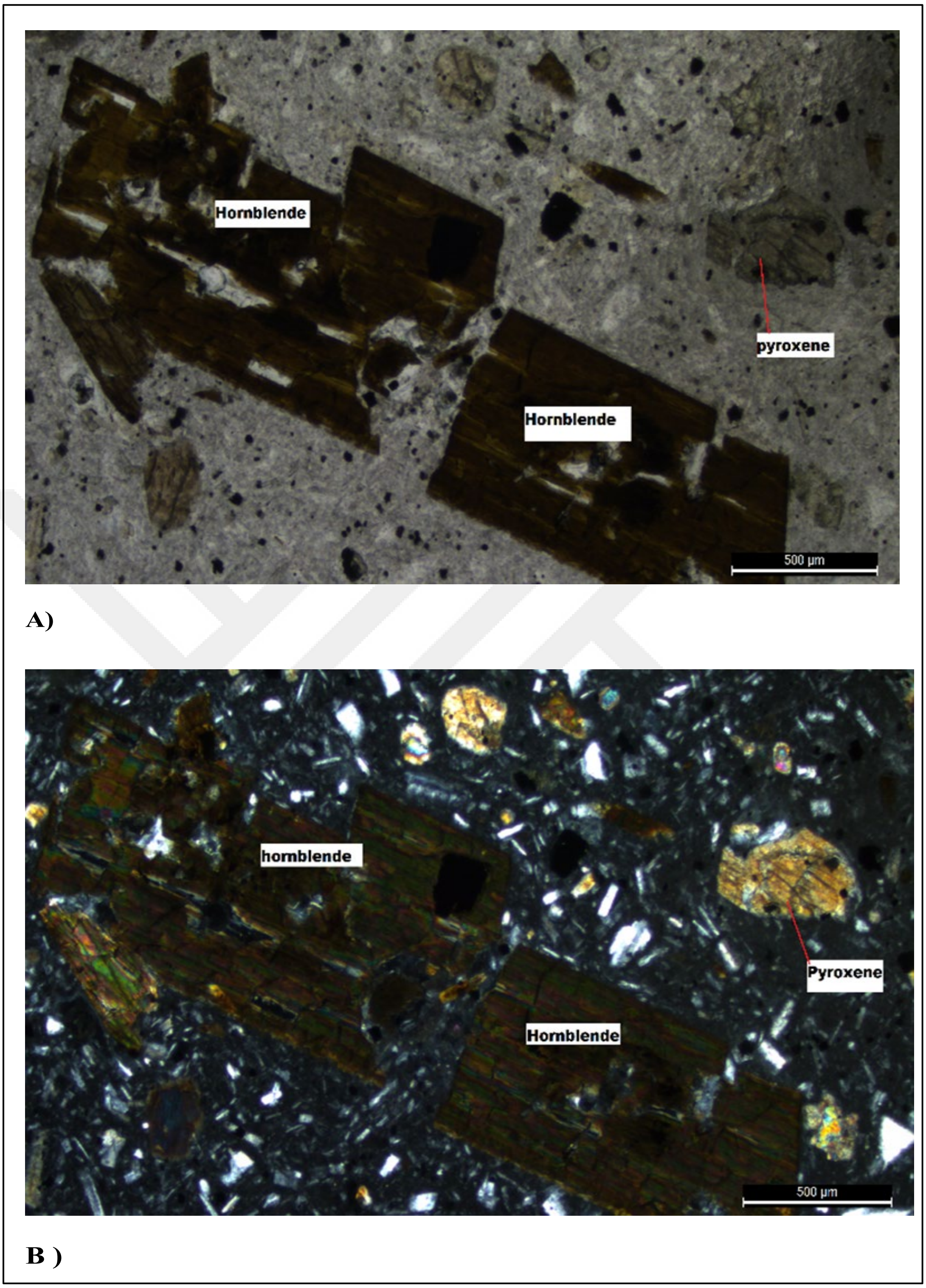
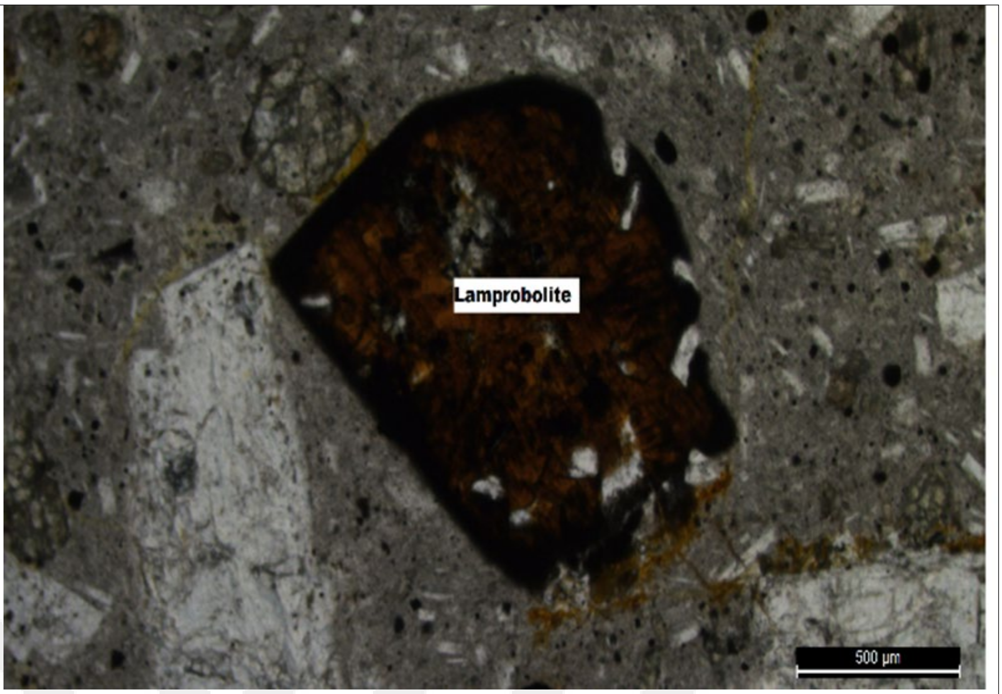


Figure 3.2 Grey andesite-mineralogical observations under plane polarised light (A) and (B) crossed polarised light (Personal archive,2019)



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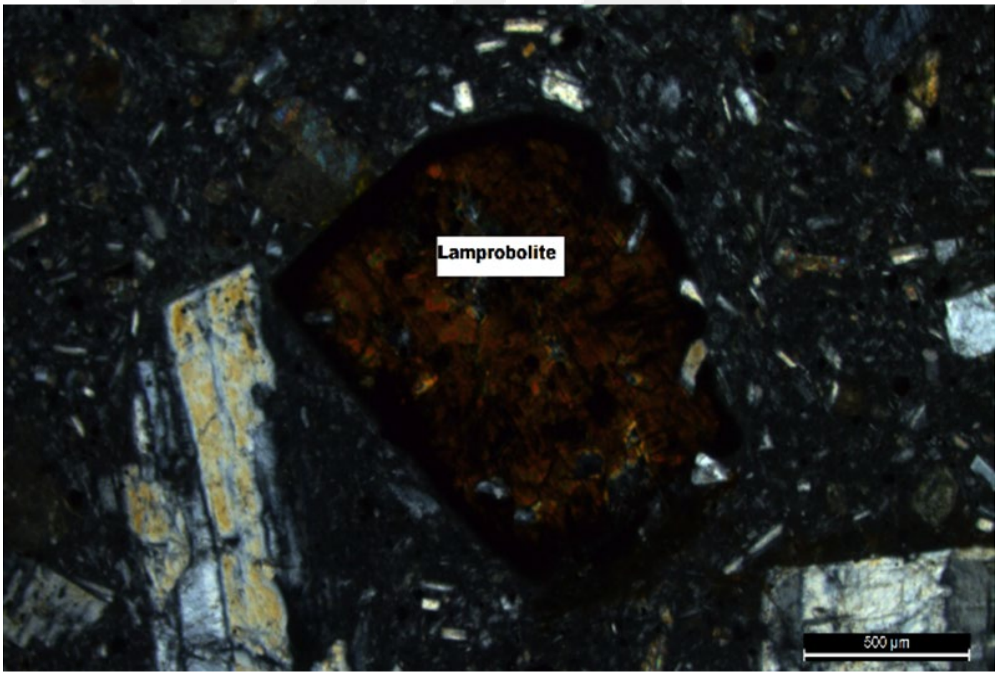

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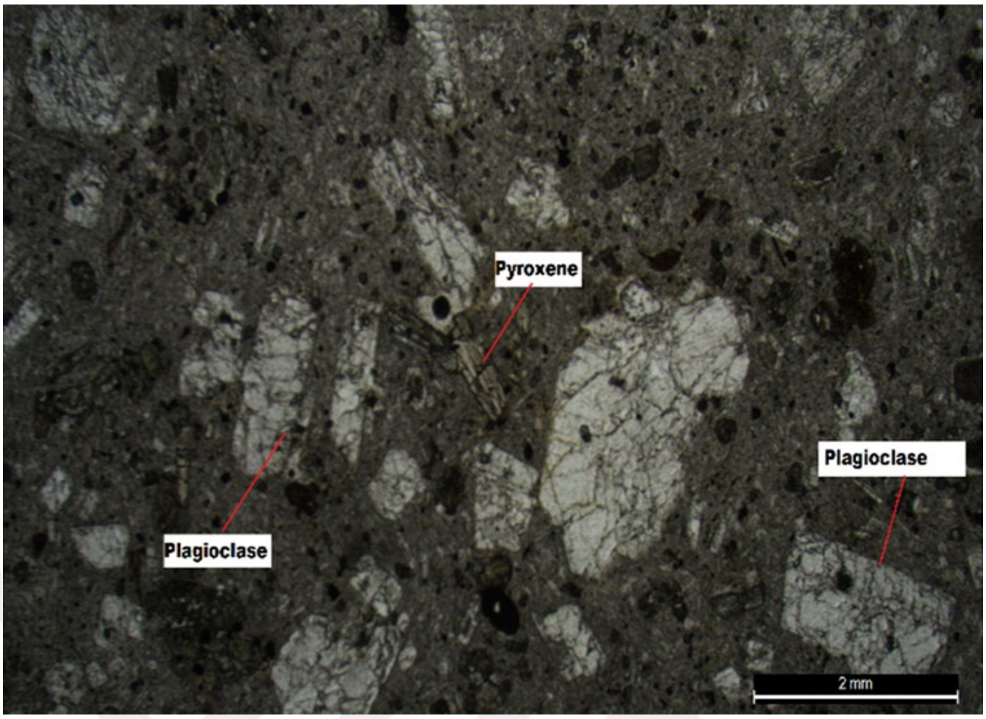
Figure 3.3 Grey andesite-mineralogical observations under plane polarised light (A) and (B) crossed polarised light (Personal archive,2019)



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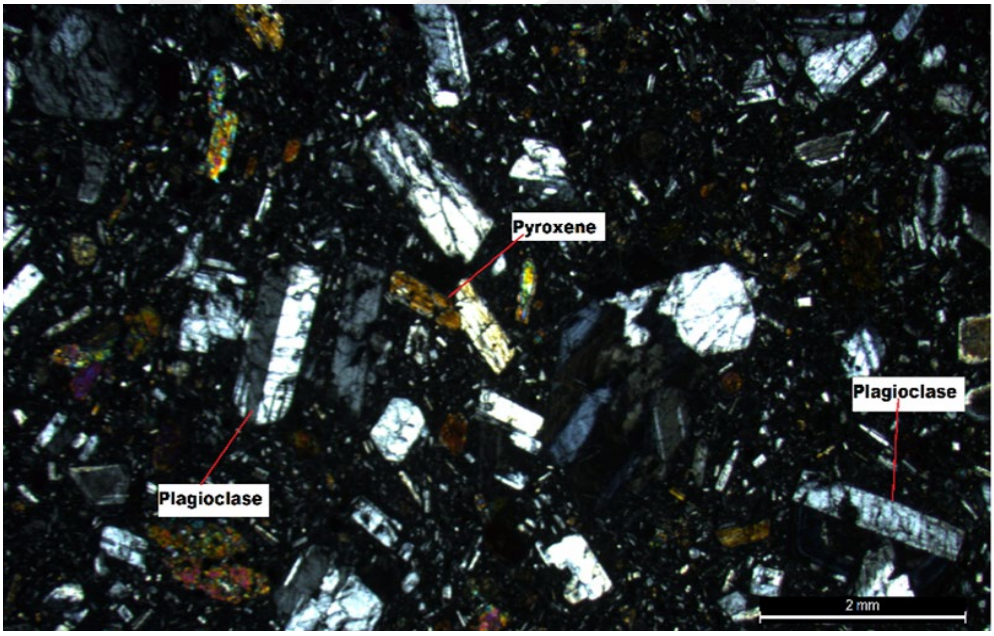


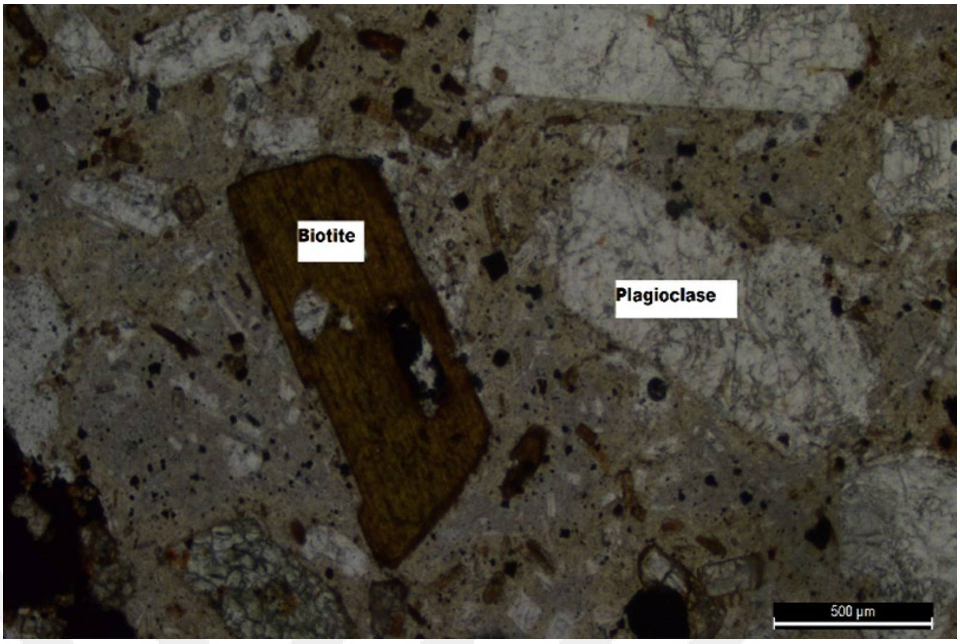
B)

Figure 3.4 Grey andesite- mineralogical observations under plane polarised light (A) and (B) crossed polarised light (Personal archive,2019)

3.1.2 Pink andesite

The minerals identified in the thin section include feldspar plagioclase, biotite, pyroxene (clinopyroxene & orthopyroxene) and lamprobolite. The specimen is very rich in feldspar plagioclase. The biotite is oxidized and dark (Figure 3.6). The minerals do not present any alteration however; they are unfilled fractures present. The specimen also indicates the slight flow band pattern. The specimen's matrices principally consist of dark glass and microlite. The microlite is principally plagioclase phenocrystals.

Figure 3.5 Images of pink andesite (Personal archive,2019)



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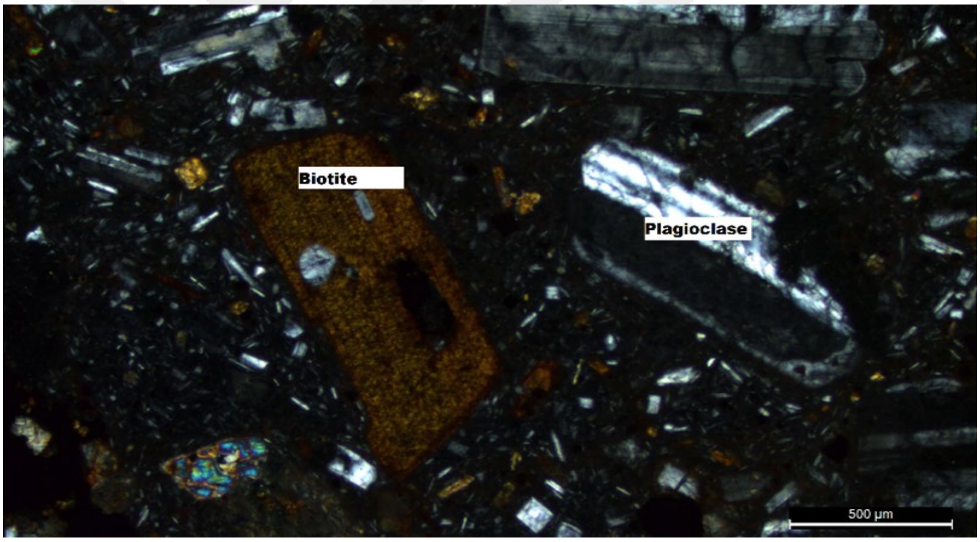

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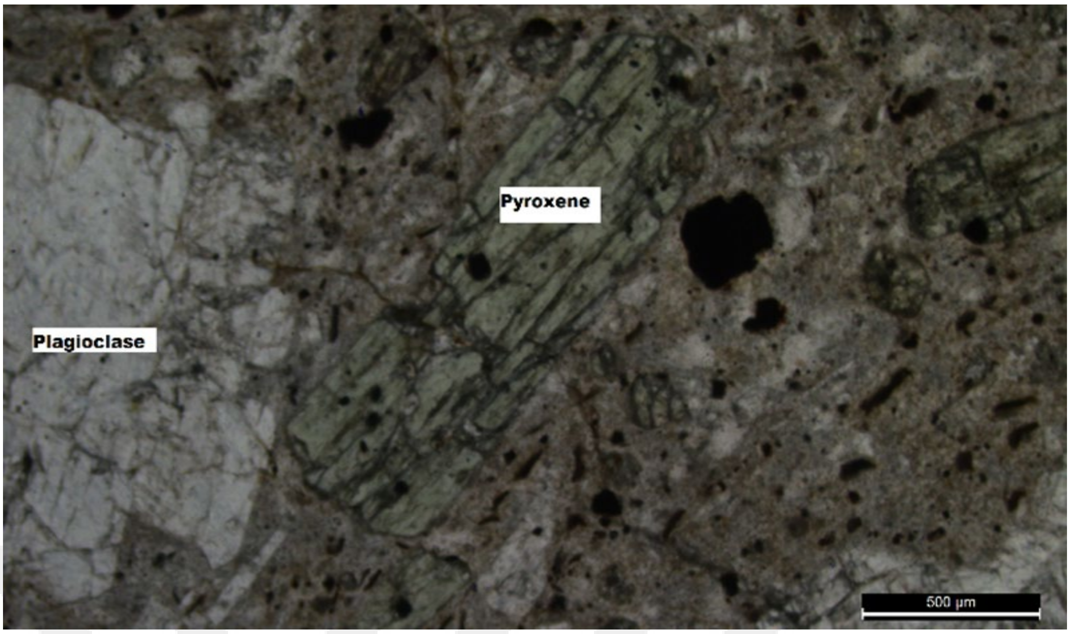
Figure 3.6 Pink andesite- mineralogical observations under plane polarised light (A) and (B) crossed polarised light (Personal archive,2019)



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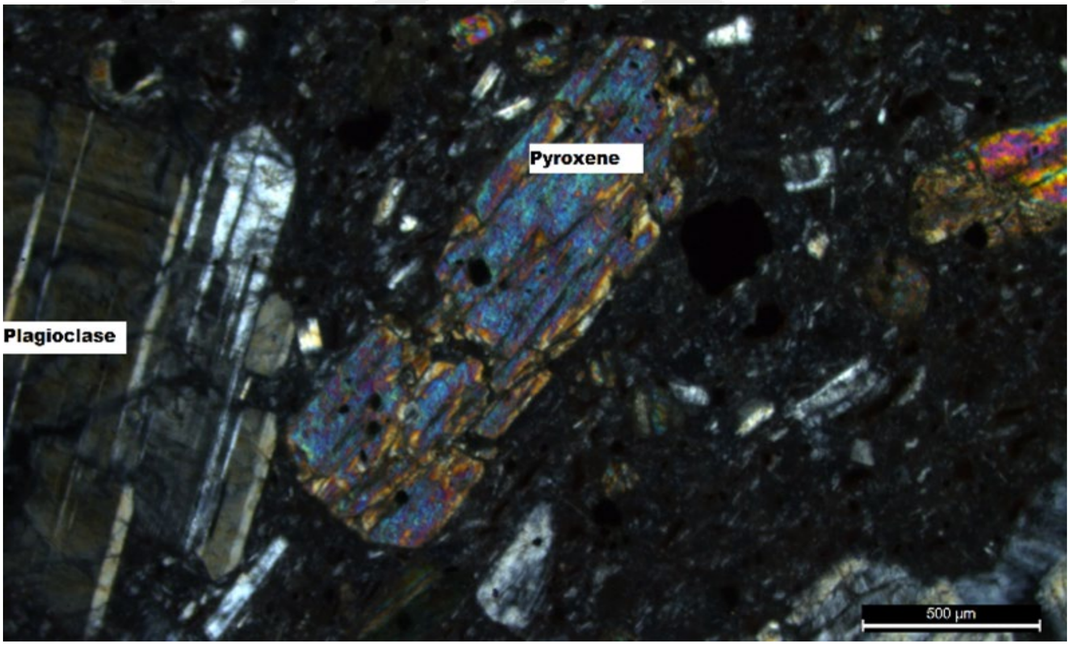
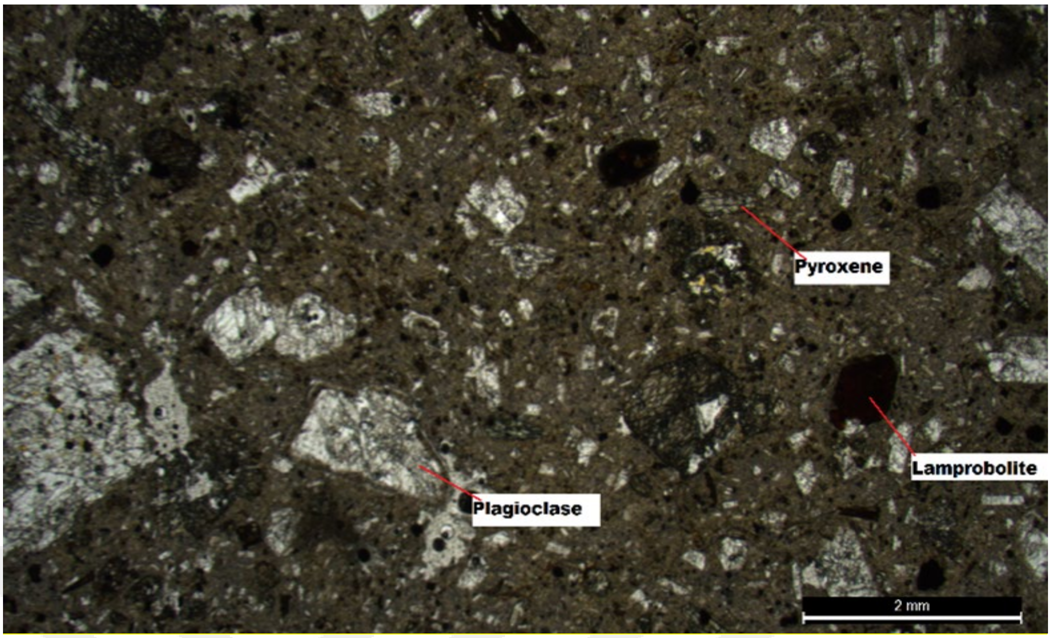


B)

Figure 3.7 Pink andesite- mineralogical observations under plane polarised light (A) and (B) crossed polarised light (Personal archive,2019)



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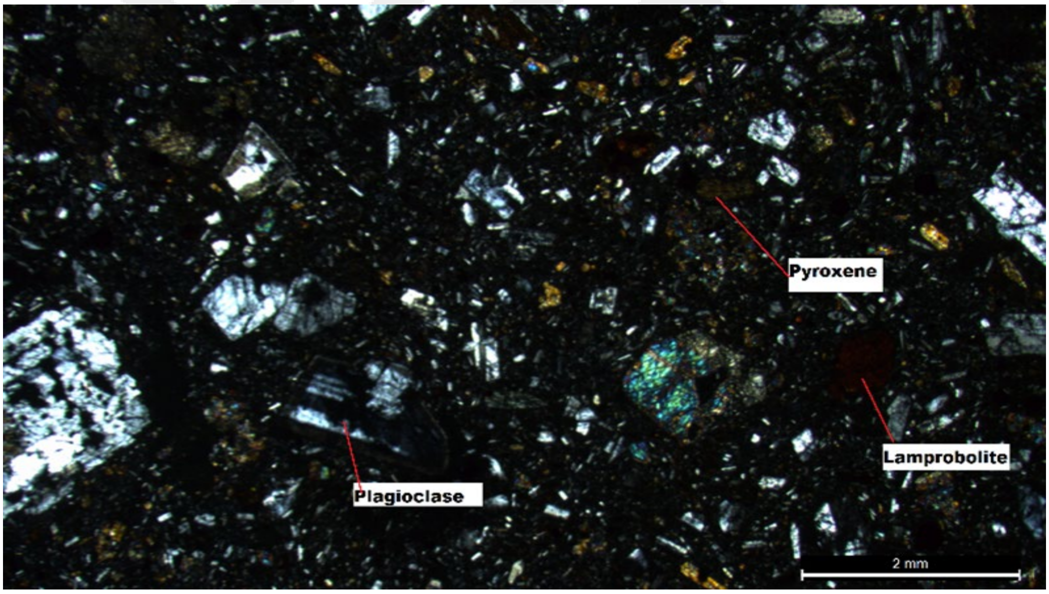

B)

Figure 3.8 Pink andesite- mineralogical observations under plane polarised light (A) and (B) crossed polarised light (Personal archive,2019*)*

3.2 Geochemical Analysis

3.2.1 Bulk Analysis via Induction Coupled Plasma Mass Spectroscopy (ICP MS)

Bulk analysis is a chemical analysis used to determine bulk chemistries for samples in the natural surface analysis group. The test is widely used to understand the petro genesis of a rock. Bulk analysis is most used in the study of igneous because it provides a chemical quantification of silica (SiO_2) whose composition in an igneous rock denote is as either mafic or felsic. The bulk analysis of the samples was obtained via a standard Induction Coupled Plasma Mass Spectroscopy (ICP MS), performed at ALS Company in Gaziemir (İzmir). The samples were prepared from pink and grey andesite blocks; powder samples were obtained from both rock types respectively. The analysis was performed for the major elements in their oxide form: K_2O, Na_2O, SiO_2, Al_2O_3, MnO, TiO_2, FeO, CaO, MgO. The results of are presented in Table 3.1. Both rock types were classed as "Andesite" according to the Total Alkali Silica diagram by Lebas et al., (1986) (Fig.3.9).

Table 3.1 Bulk analysis of andesite. Values are in units of wt. % oxide. LOI, loss on ignition

Mineral	*wt. % oxide*	Pink Andesite	Grey Andesite
SiO_2	%	59.6	61.6
Al_2O_3	%	15.4	16.15
Fe_2O_3	%	5.93	5.88
CaO	%	5.44	5.66
MgO	%	2.95	3
Na_2O	%	3.04	3.05
K2O	%	3.44	3.22
Cr_2O_3	%	0.007	0.006
TiO_2	%	0.7	0.69
MnO	%	0.1	0.1
P_2O_5	%	0.28	0.25
SrO	%	0.05	0.06
BaO	%	0.12	0.13
LOI	%	1.13	1.78
Total	%	98.19	101.58

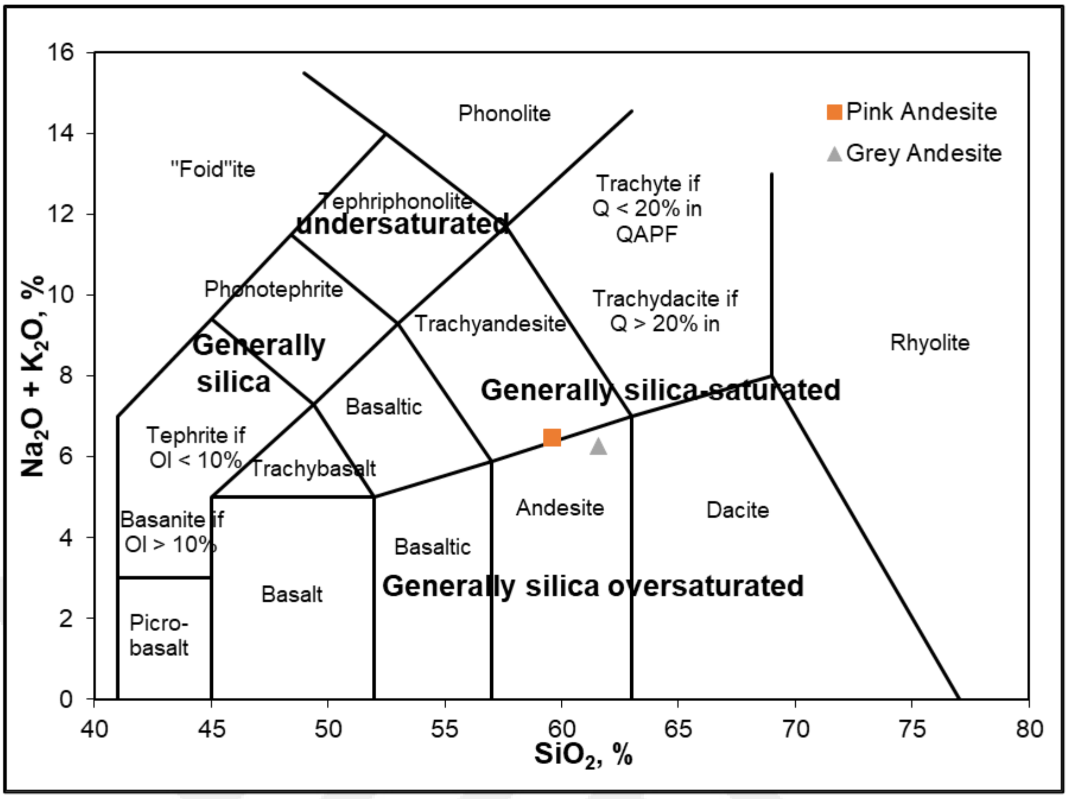

Figure 3.9 Total alkali silica diagram by Lebas et al, (1986)

3.2.2 X-Ray Diffraction Analysis (XRD)

X-Ray Diffraction (XRD) is the best modern technique for identification and quantification of the mineralogy of crystalline compounds present in rocks and soil samples. XRD is an indispensable technique in identifying the nature of clay minerals that cannot be identified by other techniques. The presence of clay mineral gives information on the behaviour of a rock under physical conditions and also influence the strength of rocks. In this study the test was used to identify the minerals in the rock samples. To effectuate this method in this study powder samples were obtained from crushing pink and grey andesite rock mass. The test was performed on unoriented samples using 2°Theta radiation . The test was performed at the Geology Engineering Department (D.E.U).

The XRD results of andesite samples obtained from X-Ray Diffraction analyses demonstrate similar diffraction graph patterns respectively for both rock types (Figure 3.10 & 3.11). The analyses identified plagioclase, potassium feldspar minerals including clay minerals mica and smectite were indicated in both samples. However, amphibole was the only mineral identified in grey andesite. The clay minerals present in both samples possibly influence physical and mechanical properties such as degree of saturation.Quantification of clay minerals in these samples was not analyzed as it was not the objective of the test.

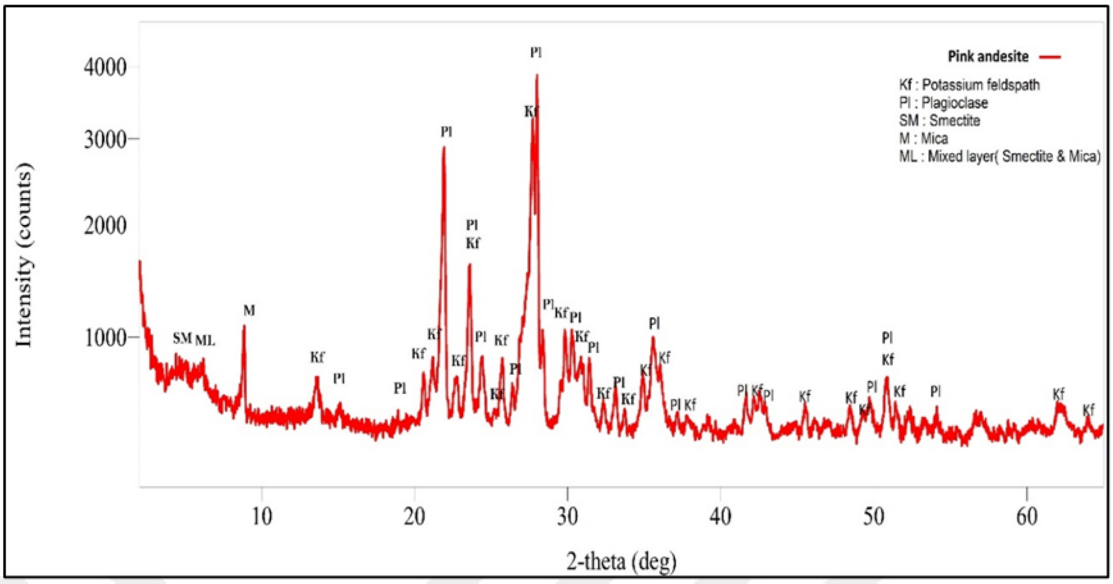

Figure 3.10 Distribution of X-ray diffraction in pink andesite

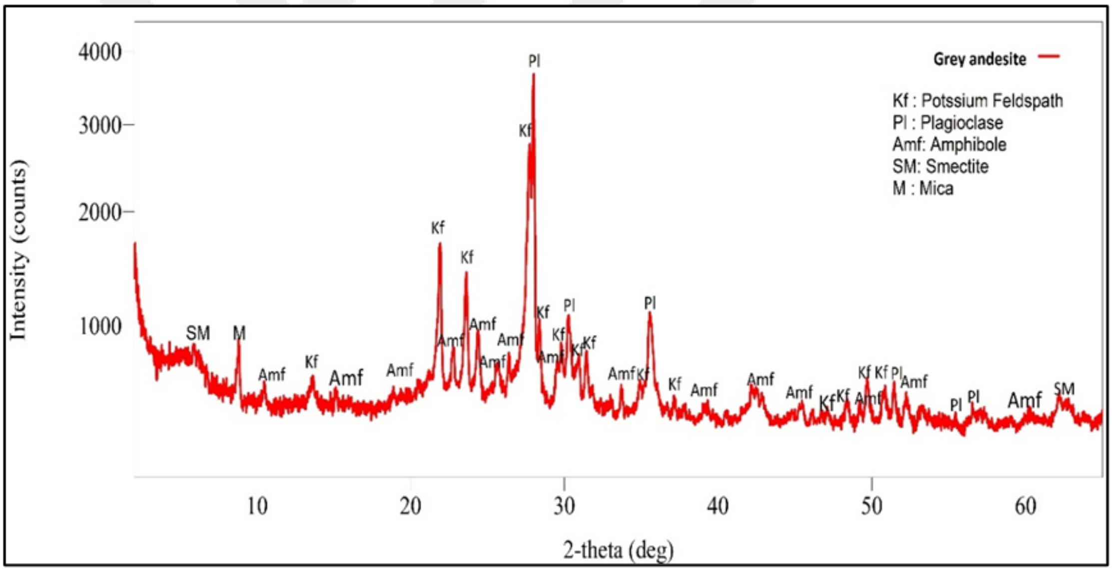

Figure 3.11 Distribution of X-ray diffraction in grey andesite

Table 3.2 Minerals identified from X-Ray Diffraction analyses

Pink Andesite	Grey Andesite
Potassium feldspath	Potassium feldspath
Plagioclase	Plagioclase
Mica	Mica
Smectite	Smectite
	Amphibole

CHAPTER FOUR
ENGINEERING GEOLOGY

The material of rocks varies indubitably in texture and composition due to their mineral composition, geological history and other environmental factors. Hence, properties of natural rocks are highly variable and irreducible (Jaeger & Cook, 2007). The tests conducted on rocks in the developmental stages of rock mechanics whose behaviours were insufficiently assessed, therefore lead to a lack of physical and mathematical empirical formulations (Mogi, 2007). Henceforth, it is significant to understand the mechanical properties of anisotropic rocks. To assess the performance of these rocks, laboratory tests are integrated.

4.1 Test outline

The laboratory test procedure consisted of five main parts; (i) physical tests, (ii) mechanical tests, (iii) accelerated weathering tests. In the physical tests, the rock samples were subjected to dry and saturated conditions to ascertain their unit weight-wave propagation velocity, porosity capacity etc. As for the mechanical tests, Uniaxial Compressive Strength (UCS) test, Brazilian Tensile Strength (BTS) test, Point Load Index ($Is_{(50)}$) test and Bohme abrasion resistance test were performed on dry and saturated rock samples, in respect to their anisotropy plane orientation. Finally, the samples were subjected to corrosive environmental conditions in other words accelerated weathering tests, these tests included wetting-drying, freezing-thawing and salt crystallization tests.

4.2 Sample preparation

The rock samples subjected to the laboratory tests are pink and grey andesite. The rock samples were prepared into cylindrical cores from 30x30x30cm block samples of the rocks, for all the mechanical tests except for the Bohme abrasion resistance test where 70x70x70mm cubes were prepared. The cores had an average diameter of 52 mm and the length was in accordance to the test they were subjected to respectively. To investigate the changes in the of the physical and mechanical properties of the rock influenced by anisotropy, the cores were cored at different anisotropic angles (0°, 30°, 45°, 60° and 90°) in function of the flow band and cooling joint geological features present in the andesite rock as demonstrated in Figure 4.1.

For all mechanical and physical tests, the samples were grouped into two categories that is dry and saturated samples. In order to correlate and compare the influence of physical properties on mechanical behaviors of the rock.

Figure 4.1 Rock coring at angle β = 45° (Personal archive,2019)

4.3 Physical properties

Physical properties are the most defining factor in rock mechanics that is because they greatly influence the strength of rock and the overall performance of a rock. In addition to they also can deduce a rock from hard to soft rocks. In this study total of 159 core samples were subjected the saturation buoyancy method to determine their physical properties. The following parameters were tabulated.

4.3.1 Specific Gravity

Specific gravity is defined as the ratio of the unit weight volume of a rock to the unit weight volume of distilled water at +4 °C. To carry out the test rock samples were crushed into fine powder using a jaw crusher and sieved though a 0.063 mm mesh. The test was carried out with the aid of pycnometer. The test procedure was carried out according to TS699 (2009). Specific gravity is expressed as follows:

$$Gs = \frac{m_e}{m_2 + m_e - m_1} \quad (4.1)$$

Where,

Gs: specific gravity

m_e: mass of sample(gr)

m_1: mass of pycnometer+ sample + distilled water (gr)

m_2: mass of pycnometer + mass of distilled water(gr)

The obtained specific gravity for the study rocks is 2.64 for grey andesite and 2.61 for pink andesite respectively as shown in table 4.1.

Table 4.1 Specific gravity values.

Rock type	N	Specific gravity	
		Mean	STD (±)
Pink andesite	2	2.61	0.05
Grey andesite	2	2.64	0.02

4.3.2 Porosity

Porosity is defined as the ratio of the total pores and total volume of a rock. It is distinguished by two types porosity, effective porosity also referred to "accessible porosity" and total porosity. Effective porosity of a rock is defined as all the rock's pore spaces accessible to fluid and gases whereas, the total porosity is defined as all the accessible pore space including all the inaccessible pores spaces. According to the definition of the two types of porosity are usually equal or different however, the difference is a very minimal. The porosity of a rock has a direct and an indirect influence on physical and mechanical properties of rock which include rock strength and weathering hence it is a very important parameter in rock performance evaluation. Effective porosity is a primary interest in weathering processes and rock strength often the relationships are correlated between these parameters. Effective porosity is expressed as follows:

$$\%\ n = \frac{V_v}{V_T} \times 100 \quad (4.2)$$

Where;

%n: effective porosity

Vv: volume of voids(cm³)

V_T: total volume (cm³)

Ws: saturated specimen mass (gr)

Wd: dry specimen mass (gr)

$Wsub$: submerged specimen mass(gr)

The total volume and volume of voids are expressed in equation 4.3 .and 4.4 respectively.

$$Vv = Ws - Wd \quad (4.3)$$

$$Vt = Ws - Wsub \quad (4.4)$$

Table 4.2 Rock classification of effective porosity according to IAEG (Anon, 1979)

Classification	Effective Porosity (%)
Very Low	<1
Low	1-5
Medium	5-10
High	10-30
Very High	≥30

Table 4.3 Effective porosity mean values

Rock Type	N	Mean effective porosity (%)		Classification by Anon (1979)
		Mean	STD (±)	
Pink Andesite	60	5.91	1.65	Medium
Grey Andesite	99	2.89	0.99	Low

According to Anon (1979) rock classification, grey andesite is classified as “ low porosity” with the value of 2.89% and pink andesite is classified as “medium porosity” with a value of 5.91% respectively (Table 4.3)

Total porosity

Total porosity of the pink and grey andesite was expressed using the formula below.

$$n = 1 - \left(\frac{\gamma_{dry}}{G_s}\right) \times 100 \quad (4.5)$$

Where:

n: total porosity (%)

γ_{dry}: dry unit weight

Gs: specific gravity

The total porosity indicated in this study is 7.83% for pink andesite and 5.31% for grey andesite (Table 4.5).

Table 4.4 Total porosity mean values

Rock type	Total porosity (%n)
Pink andesite	7.83
Grey andesite	5.31

4.3.3 Unit weight

The unit weight is defined as the ratio of mass and volume of a rock material. The unit weight of rock affects other rock properties i.e. when the unit weight is low it demonstrates a high porosity and a high-water absorption capacity. Therefore, presence of pores in intact rock material decreases its strength and increase the rate of deformability. The pores can also affect the unit weight in that the increase in pores decreases the unit weight significantly. As stated by Erdogan and Yavuz (2004). A rock’s low unit weight demonstrates a low durability and a high unit weight a high durability. To measure these indexes, weight measurements were obtained from core cylindrical samples 99 grey and 60 pink andesite were obtained by using saturation and buoyancy techniques according to (ISRM, 1985). The samples were dried in an oven at 105° and the weight to obtain the dry unit weight. To measure the saturated unit weight the rock samples were left in distilled water for 24hrs and weighed to obtain the saturated mass. The dry and saturated unit weight are expressed as follows:

Dry unit weight :

$$\boldsymbol{\gamma}_{\mathbf{dry}} = \frac{Wd}{V_T} \times 9.81 \quad (4.6)$$

Where;

γ_{dry}: dry unit weight (kN/m³)

Wd: dry mass (gr)

V_T: total volume (cm³)

Saturated unit weight:

$$\gamma_{Sat} = \frac{W_{Sat}}{V_T} \times 9.81 \tag{4.7}$$

γ_{sat}: saturated unit weight (kN/m³)

W_{sat}: saturated mass (gr)

V_T : total volume (cm³)

The dry unit weight values obtained for pink andesite and grey andesite are 23.60 kN/m³ and 24.34 kN/m³ respectively. While the saturated unit weight values indicated in this study are 24.18 kN/m³ and 24.63 kN/m³ respectively for pink and grey andesite. The distinct between difference in the unit weight values between the dry and saturated unit weight values indicate that dry unit weight for two rock types are affected by the saturation of water. However, the difference between the dry and saturated weight is greater in the pink andesite than in the grey andesite (Figure 4.2).

Based on Anon (1979) rock classification indicated that the unit weight of pink and grey andesite is moderate (Table 4.6).

Table 4.5 Mean values of dry and saturated unit weight

Rock Type	N	Dry Unit Weight (kN/m³)		Saturated Unit Weight (kN/m³)		Engineering classification by IAEG
		Mean	STD(±)	Mean	STD (±)	
Pink Andesite	60	23.60	0.81	24.18	0.70	Moderate
Grey Andesite	99	24.34	0.99	24.63	0.74	Moderate

Table 4.6 Unit weight rock classification according to IAEG (Anon, 1979)

Classification	Unit weight (g/cm³)
Very Low	<1.8
Low	1.8-2.2
Moderate	2.2-2.55
High	2.55-2.75
Very High	>2.75

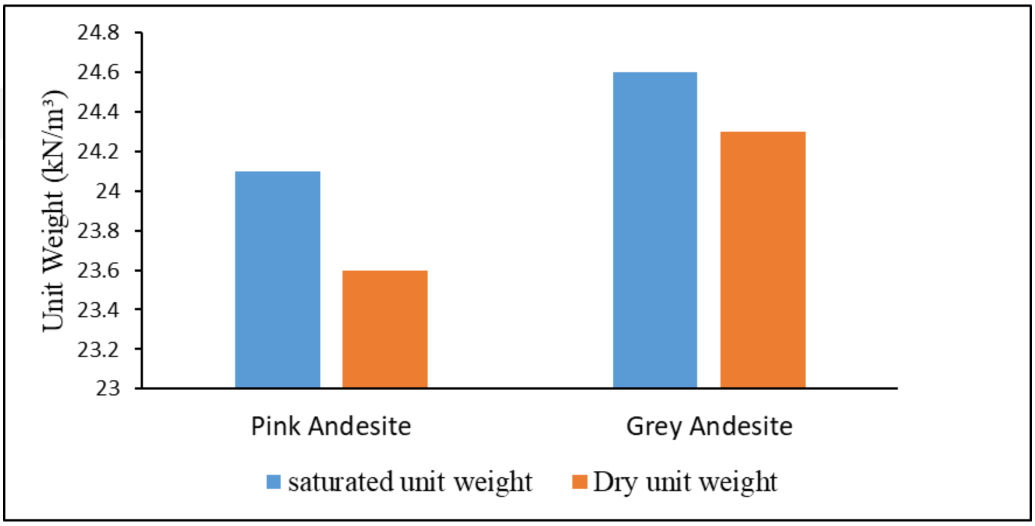

Figure 4.2 Dry and saturated unit weight graph illustration of grey and pink andesite

4.3.4 Relationship between unit weight and porosity

The relation between porosity, saturated unit weight and dry unit weight of pink and grey andesite was analysed. Strong linear regression values were observed from inverse linear relation between the saturated unit weight and porosity and between the dry unit weight and porosity in both rock types. The strong linear values of the data sets proved that the regression linear equations of the lines are viable. Henceforth, the values of either of the properties is highly dependable of the other. The graphs and regression equations for these relations are presented below.

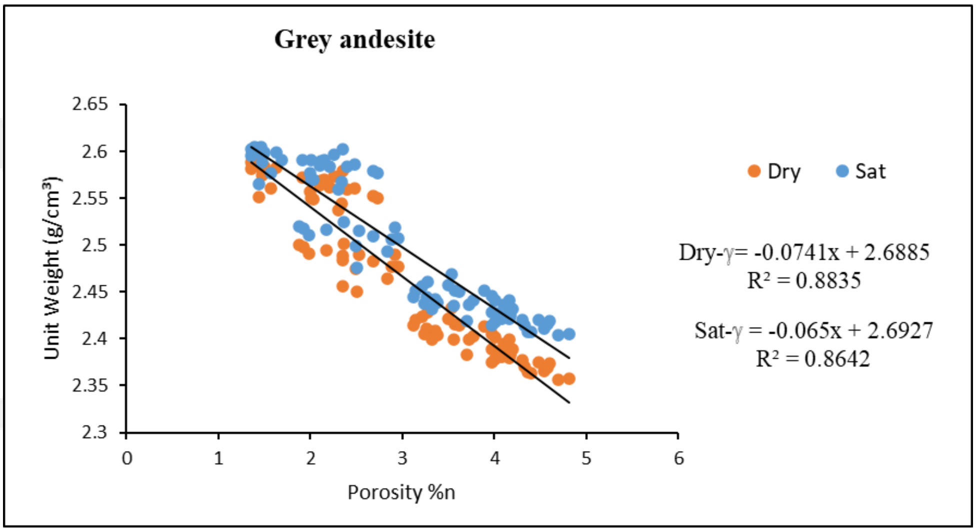

Figure 4.3 Relations between unit weight and porosity (grey andesite)

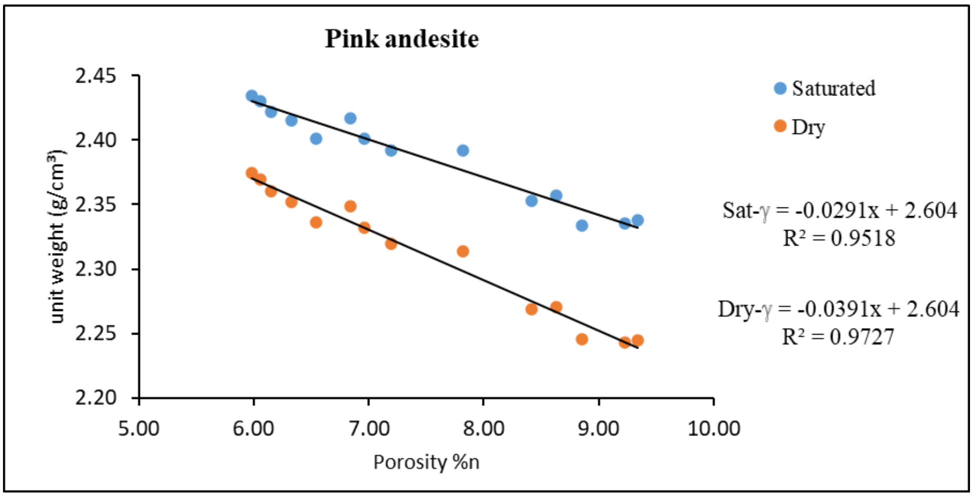

Figure 4.3 Relations between porosity and unit weight (pink andesite)

4.3.5 Void Ratio

Void ratio is defined as the ratio of the volume of voids in the volume of a rock. The void ratio values for this study are indicted in Table 4.7. The void ratio was calculated as shown in equation (4.8).

$$e = \left(\frac{n}{100 - n}\right) \times 100 \tag{4.8}$$

Where:
e: void ratio (%)
n: effective porosity (%)

The void ratio values indicated in this study is 6.31% for pink andesite and 2.97% for grey andesite respectively (Table 4.7).

Table 4.7 Void ratio values of pink and grey andesite

Rock Type	Void ratio (%)		
	N	Mean	STD (±)
Pink Andesite	60	6.31	1.86
Grey Andesite	99	2.97	1.07

N: number of samples; STD: standard deviation

4.3.6 Water Absorption under Atmospheric Pressure

The objective of this test is to determine the amount of water absorbed by an intact rock under atmospheric pressure, expressing percentage the tests were performed according to TS699 (2009) and BSI (1975).

$$Absorption\ value\ by\ weight = \frac{W_s - W_d}{W_d} \times 100 \tag{4.9}$$

Where:

Ws-is the specimen's saturated mass (gr)

Wd-is the specimen's dry mass (gr)

$$Absorption\ value\ by\ volume = \frac{Ws - Wd}{V_T} \times 100 \tag{4.10}$$

Where:

V_T- is the total volume of the specimen cm^3

Based on the results pink andesite has a considerably high-water absorption capacity under atmospheric pressure by weight and volume with the values 2.5% and 6.3% respectively compared to grey andesite that is considerably low with values 1.2% and 3.0% (Table 4.8).

Table 4.8 Mean measurements of water absorption by weight and by volume

Rock type	N	Watm by weight %		Watm by volume %	
		Mean	STD (±)	Mean	STD (±)
Pink andesite	60	2.5	0.76	6.3	1.65
Grey andesite	99	1.2	0.4	3.0	0.99

4.3.7 Water Absorption Under Vacuum Pressure

The objective of this test is to determine the amount of water being, absorbed by rock under vacuum pressure. Water absorption under vacuum pressure test was performed according to ISRM (1981) on the same samples used for the water absorption under atmospheric pressure test. During the tests, the water absorption percentages by weight and volume were determined.

Based on the test results, it is indicated that the grey andesite has a considerably low water absorption under vacuum pressure compared to that of pink andesite as show in Table 4.9.

Table 4.9 Average measurements of water absorption under vacuum pressure

Rock Type	N	Water absorption by weight%		Water absorption by volume%	
		Mean	(±) STD	Mean	(±) STD
Pink Andesite	9	4.3	1.1	11.31	2.7
Grey Andesite	9	1.4	0.2	3.65	0.42

4.3.8 Sonic Velocity Test

Ultrasonic or sonic sound wave propagation through large rock samples is a major interest in rock engineering in as it evaluates the intact strength of the rock and detects inchoate or apparent flaws such as cracks, cavities etc. The performance of this method is highly dependent on pressure and saturation of the rocks sample.

The sonic velocity test is intended as a method to determine the velocity of propagation of elastic waves in rocks (ISRM, 1981).The test is important in as the sonic velocity parameter correlates with several physical and mechanical parameters of a rock material. Most importantly it provides information on the porosity and fissuring of a rock material. In addition, it also determines the anisotropy in a rock that is the P-wave varies in direction. Sonic velocity was tested on andesite core samples on their both dry and saturated states in respective to their anisotropy angle. An impulse was conveyed on the specimen using the ultrasonic pulse method to measure the Longitudinal wave (P) velocity. To calculate the velocity, the time for transient pulse to the traverse the length of the specimen is used. The velocity formula is as follows:

$$V=\frac{L}{t}\ (m/s) \tag{4.11}$$

Where,

V: Velocity(m/s)

L: length of specimen(m)

t: time(s)

Figure 4.4 Ultrasonic pundit device in use on pink andesite (Personal archive,2019)

Table 4.10 Average values of P-wave velocity in function of anisotropy angle for grey andesite

Anisotropy Angle (°)	N	P-wave velocity (m/s)	
		Saturated (±) STD	Dry (±) STD
0	15	4966.39 ± 139.38	4534.28 ± 259.61
30	15	4979.49 ± 79.61	4642.59 ± 137.96
45	20	5077.34 ± 271.49	4708.15 ± 259.77
60	12	5127.88 ± 220.67	4753.72 ± 338.54
90	16	5133.45 ± 304.57	4768.67 ± 264.10

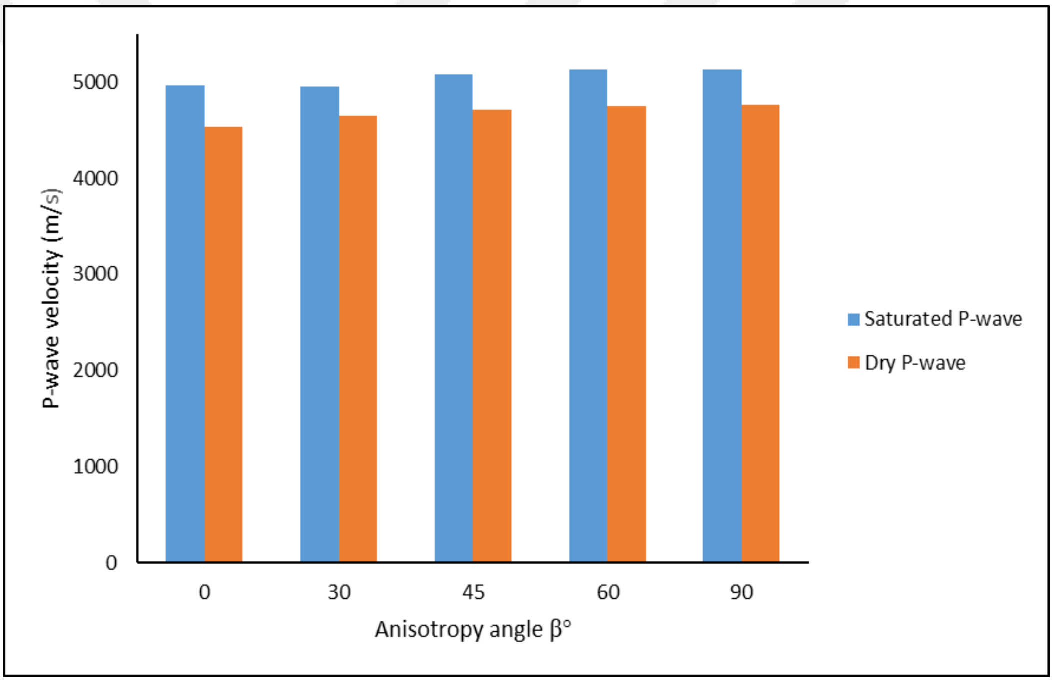

Figure 4.5 Graphic illustration of the P-wave velocity in function of anisotropy angle of grey andesite

Table 4.11 Average measurements of P-wave sonic velocity in function of anisotropy angle for pink andesite

Anisotropy Angle (°)	N	P-wave velocity (m/s)	
		Saturated (±) STD	Dry (±) STD
0	11	4272.97 ± 389.16	3859.04 ± 393.13
30	11	4410.84 ± 426.52	4016.42 ± 407.33
45	16	4446.41 ± 280.22	3965.91 ± 344.25
60	11	4604.55 ± 280.75	4042.67 ± 363.24
90	11	4689.13 ± 122.60	4152.13 ± 153.06

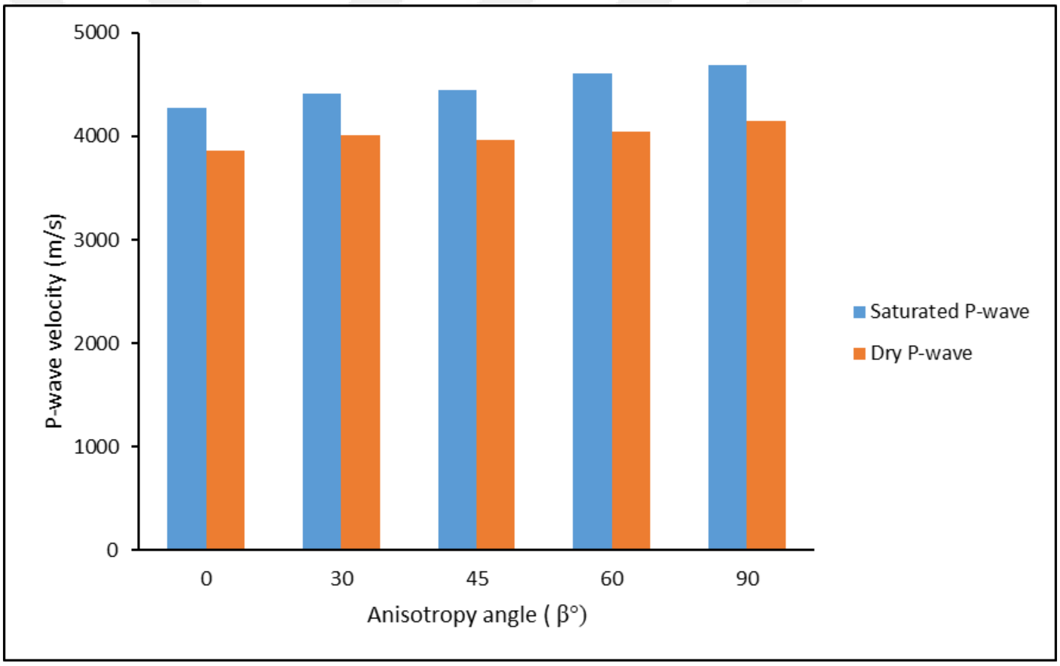

Figure 4.6 Graphic illustration of the P-wave velocity in function of anisotropy angle of pink andesite

Table 4.12 P-wave velocity classification after (Anon, 1979)

Vp (m/s)	Classification
< 2500	Very Low
2500-3500	Low
3500-4000	Moderate
4000-5000	High
> 5000	Very High

The compression wave velocity (P-wave) in function of the anisotropy angle (β°) recorded in grey andesite are between 5133.45-4966.39m/s for saturated samples, and 4768.67-4534.28 m/s for dry samples. While in pink andesite the velocity values are between 4689.13-4272.97m/s for saturated samples, and 4152.13 -3859.04m/s for dry samples. The maximum velocity values were indicated in grey andesite for saturated and dry samples, with values 5133.45m/s and 4768.67m/s respectively (Table 4.10 and 4.11).

The of velocity changes of pink and grey andesite in function of the orientation, indicated maximum velocity at anisotropy angle β= 90° and minimum values at β= 0° respectively for saturated and dry samples (Table 4.10 and 4.11). The variations of P-wave velocity in relation to anisotropy angle are illustrated in Figure 4.6 and 4.7.

Based on the compression wave velocity (P-wave) classification after Anon (1979), saturated samples are classified as “very high” in grey andesite and “high” in pink andesite, while the dry specimens are classified as “high” in grey andesite and moderate in “pink andesite” respectively.

4.3.8.1 Degree of velocity Anisotropy

The determination and evaluation of wave velocity anisotropy of intact rock, have been extensively used in past to assess the performance of a rock considering that the measurement of ultrasonic transmission is relatively a simple method.

The quantification of wave velocity anisotropy was proposed by Tsidzi (1997) the velocity anisotropy index (VA) was proposed after a series of tests on metamorphic rocks. The anisotropy index classification proposed is given in Table (4.14). The index is expressed as follows:

$$VA = \frac{V_{max} - V_{min}}{V_{mean}} \% \tag{4.12}$$

Where,

V_{max} : maximum ultrasonic wave velocity

V_{min} : minimum ultrasonic wave velocity

V_{mean} : mean ultrasonic wave

In view of the type of rock presented in this study the anisotropy index ratio (Ivp) was expressed as follows:

$$I_{VP} = \frac{V_{P(max)}}{V_{P(min)}} \tag{4.13}$$

The maximum compression wave velocity Vp(max), occurs when the wave propagation is parallel to the planes of anisotropy in this case angle β= 90° whereas Vp(min) is the minimum compression wave velocity (P-wave) m/s, occurs when the wave propagation is perpendicular to the planes of anisotropy in this case β= 0°.

In this study the ratio determines and quantifies, the wave velocity anisotropy and its correlation with strength anisotropy present in an intact rock. The anisotropy ratio exhibited by the study rocks are presented in Table 4.13.

Table 4.13 Anisotropy index ratio values

Rock type	P-wave anisotropy index (Ivp)		Degree of anisotropy (Tsidzi, 1997)
	Saturated	Dry	
Pink andesite	1.09	1.07	Isotropic
Grey andesite	1.03	1.05	Isotropic

According to Tsidzi (1997) classification after the ultrasonic wave velocity test was performed on saturated and dry specimens of both rock types, it was found that the anisotropy degree exhibited by grey andesite classified as “isotropic” whereas, pink andesite classified as “Isotropic”.

Table 4.14 Degree of velocity anisotropy classification according to ultrasonic wave velocity (Tsidzi, 1997)

Degree of velocity anisotropy VA (%)	Descriptive term
<2	Isotropic
2-6	Fairly anisotropic
6-20	Moderately anisotropic
20-40	Highly anisotropic
>40	Very highly anisotropic

4.4 Mechanical Tests

Changes of rock strength in an intact rock in respective to anisotropy plane orientation exhibited by pink and grey andesite rock are derived from mechanical tests, the most important parameters assessed from the mechanical tests for this study are Uniaxial Compressive Strength (UCS), Brazilian Tensile Strength (BTS) and Point Load Index($Is_{(50)}$). In addition, the parameters are an input in the classification of anisotropy thus quantify and qualify. The obtained results and classifications from these parameters are compared and further correlated to with other experimental parameters. All the parameters are assessed according to ISRM (2007).

The results of mechanical tests are presented in accordance to the rock type. The mechanical parameters determined in respective to the anisotropy plane orientation and the physical state for each rock type.

4.4.1 Uniaxial Compressive Strength Test

The Uniaxial compressive strength (UCS) test is one of the important tests for determining and classification of strength of a rock (ISRM, 1981). The test determines the compressive strength (σ_c) which characterizes and classifies the strength of an intact rock. In addition, the parameter is also an input in degree of anisotropy in rock mass. The test is applied on cylindrical cores samples with a ratio of length to diameter 2-2.5 whose diameter is approximately 54 mm (ISRM, 1981). In order to assess the difference in strength in respective to anisotropy plane orientation and classify anisotropy, the samples were core at different angle orientations where, β= 0°, 30°, 45°, 60° and 90°. The test was carried out in a motorized hydraulic compression machine at the rock mechanics laboratory at Dokuz Eylul university. The loading was applied perpendicular to the cores in function of their anisotropy plane orientation as demonstrated in Figure 4.8. The results are indicated in respective of the anisotropy plane after failure. The strength of anisotropy index is calculated using the maximum and minimum compressive strength suggested by Ramamurthy,(1993). The compressive strength was calculated using the maximum specimen failure and the area the bearing surface (ISRM, 1981).

$$\sigma c = \frac{W}{A} \tag{4.14}$$

Where;

σc: compressive strength of sample (MPa)

W: Maximum load (N)

A: Area of bearing surface (mm^2)

The strength anisotropy index is given as:

$$Rc = \frac{\sigma c(\max)}{\sigma c(\min)} \tag{4.15}$$

Where;

R_c: strength anisotropy index ratio

σ_c(max): maximum compressive strength exhibited at a given inclination angle (MPa)

σ_c (min): minimum compressive strength exhibited at a given inclination angle (MPa)

Figure 4.7 Uniaxial compression hydraulic machine (Personal archive,2019)

Table 4.15 Overall mean values of uniaxial compressive strength

Rock type	N	Saturated σ_c (MPa) Standard deviation (±)	N	Dry σ_c (MPa) Standard deviation (±)
Pink andesite	31	53.94 ± 21.24	26	85.88 ± 28.78
Grey andesite	51	72.16 ± 18.03	46	98.9 ± 19.9

The overall uniaxial compressive strength results in respective of their physical state are shown in table 4.15. The saturated mean values recorded for are 53.94 and 72.16 MPa for pink and grey andesite respectively. While the dry mean values indicated are 85.88 MPa in pink andesite and 98.9 MPa in grey andesite respectively.

Based on the obtained results, saturated and dry grey andesite samples classified as “high strength” while pink andesite classified as “medium strength” for saturated samples and “high strength” for dry respectively according to ISRM (1981) uniaxial compressive strength classification (Table 4.16).

Table 4.16 Uniaxial compressive strength classification (ISRM, 1981)

Classification term	Saturated samples	Dry samples	Uniaxial compressive strength (MPa)
Very High Strength			>200
High Strength	Grey andesite	Grey andesite, pink andesite	60-200
Medium Strength	Pink andesite		20-60
Low Strength			6-20
Very Low Strength			<6

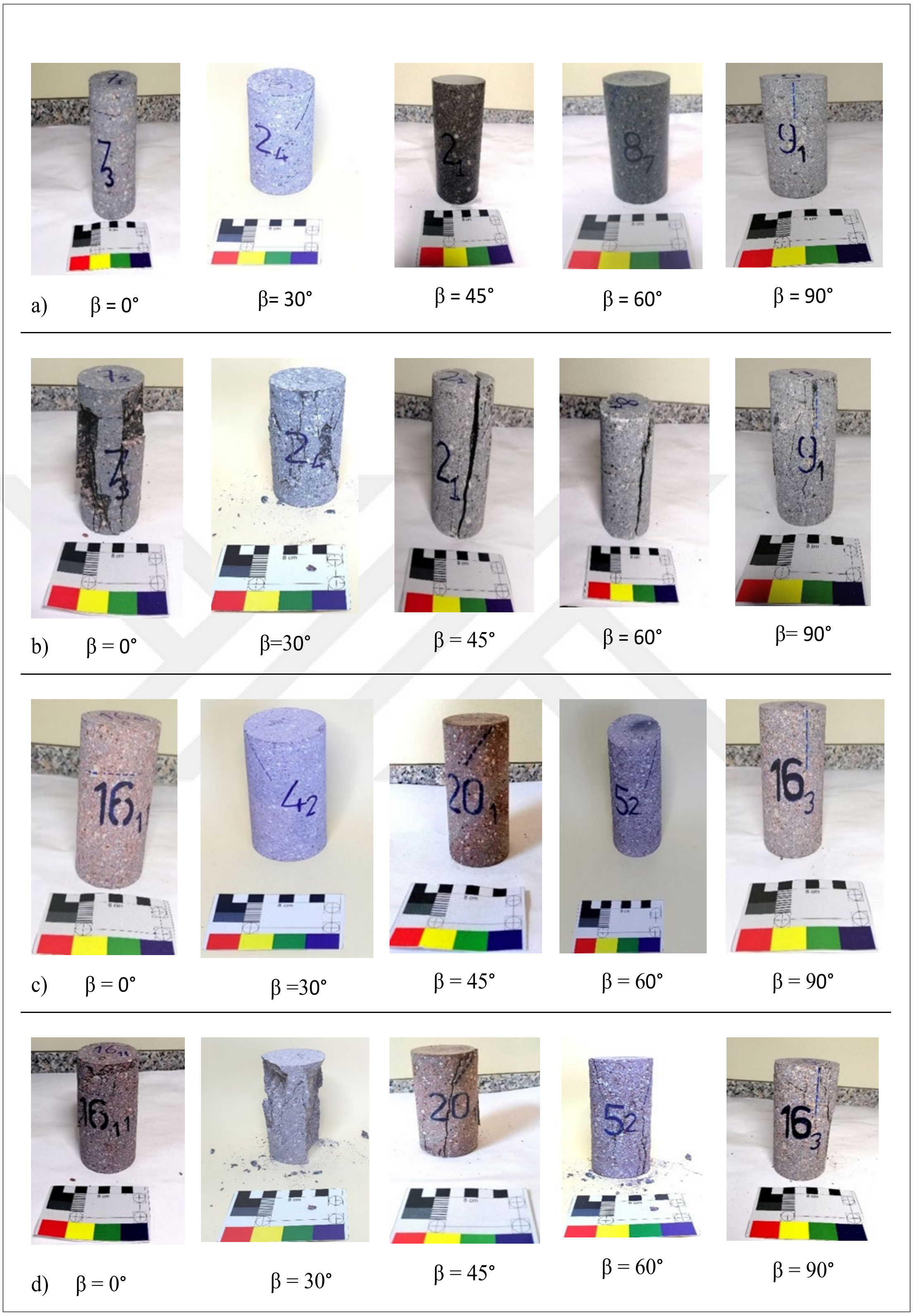

Figure 4.8 Uniaxial compressive strength test samples at respective anisotropy angle; (A) Grey andesite before test (B) Grey andesite after test, (C) Pink andesite before test and (D) Grey andesite after test (Personal archive,2019)

4.4.1.1 Strength anisotropy

Grey Andesite

Uniaxial Compressive Strength (UCS) of dry and saturated in respective of the anisotropy angle (β) of grey andesite respectively are presented in table 4.17. The specimens are subjected to loading at a variation of anisotropy angle 0, 30, 45, 60 and 90 degrees. There is a significant variation of UCS at different inclination angles. The samples maximum strength for saturated and dry samples is indicated a at β= 90° with values 79.96 and 110.74 MPa and the second maximum at β= 0° with values 79.87 and 108.08 MPa respectively. The minimum strength for saturated and dry samples, was recorded at β=45° with values 60.23 and 84.33 MPa and the second minimum at β=30° with values 67.78 and 101.96 MPa respectively. Conclusively the specimen's maximum strength is close to 0° and 90° while the minimum strength is close to 30° and 45°. However, the difference between the maximum and minimum is very minimal which could influence the intensity of strength of anisotropy exhibited by the rock mass.

The changes in strength in function of the anisotropy angle, the mean values of the dry and saturated and their average UCS results are illustrated on a graph to anisotropy angle as shown in figure 4.9.

Table 4.17 Mean values of uniaxial compressive strength (MPa) at different inclination angles for grey andesite

Anisotropy Angle °	Saturated UCS (MPa)			Dry UCS (MPa)		
	N	Mean	±STD	N	Mean	±STD
0	14	79.87	21.43	13	108.08	19.9
30	11	67.78	10.31	8	101.96	14.8
45	11	60.23	4.71	11	84.33	15.0
60	6	72.51	8.97	6	92.52	9.5
90	9	79.96	14.24	8	110.74	20.8

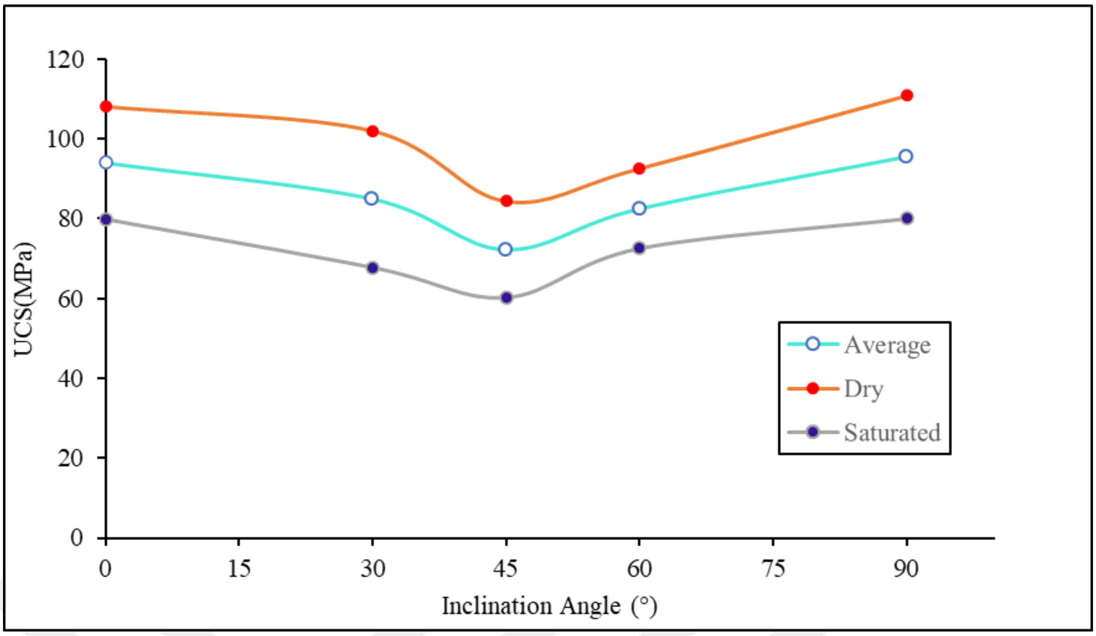

Figure 4.9 Variation of Uniaxial Compressive Strength in function of anisotropy angle graph (grey andesite)

Pink Andesite

Uniaxial Compressive Strength (UCS) of dry and saturated grey andesite respectively are presented in table 4.18. The specimens are subjected to anisotropy plane angle θ = 0°, 30°, 45°, 60°, and 90°. There is a significant change of UCS in respective to inclination angle. In order to observe the mechanical changes averages of the dry and saturated UCS results are interpolated on a graph to anisotropy angle. It's is noted that the UCS in dry and saturated specimens behave in similar way at different angles, notably the maximum strength occurred at β=90° with values 85.2 and 111.18 MPa respectively for saturated and dry samples whereas, the minimum strength values for saturated samples 36.5 and 58.82 MPa for dry samples were indicated at β= 45°. The observed strength has a significant difference between the maximum and minimum this be accredited to the presence of distinct flow bands that are perpendicular to the loading in pink andesite. Figure 4.11 presents the plotted UCS results of saturated and dry samples respective to the inclination angle including the interpolated average of the two states.

Table 4.18 Mean values of Uniaxial Compressive Strength (UCS) at different inclination angle (pink andesite)

Anisotropy Angle (°)	Saturated UCS (MPa)			Dry UCS (MPa)		
	N	Mean	STD	N	Mean	STD
0	6	65.1	19.5	5	93.23	11.23
30	6	40.5	7.2	5	51.21	24.07
45	8	36.4	7.2	6	58.82	13.6
60	5	70.6	3.8	5	86.34	17.61
90	5	85.2	16.5	6	111.18	16.12

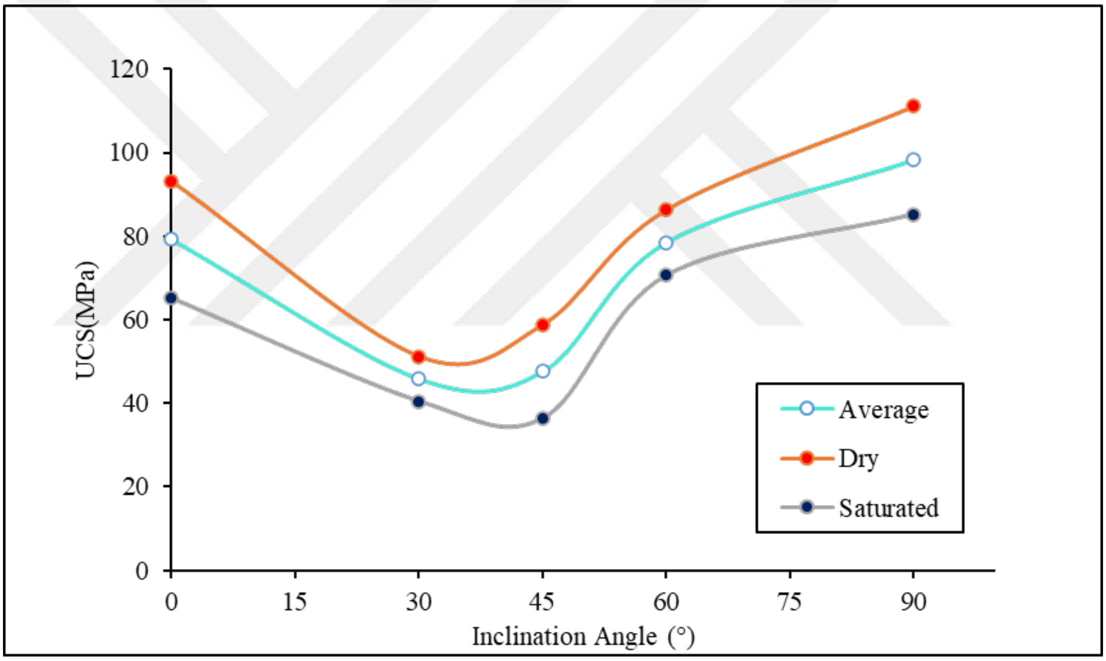

Figure 4.10 Variation of Uniaxial Compressive Strength in function of anisotropy angle graph for pink andesite

4.4.1.2 Uniaxial compressive strength anisotropy index ($I\sigma_c$)

The uniaxial compressive strength anisotropy index($I\sigma_C$) has been widely used in several engineering structural studies as a quantitative input to evaluate the intensity of anisotropy exhibited by a rock mass. In this study equation (4.15) proposed by Ramamurthy (1993) was used. The values obtained presented in respective of the physical state of the samples are pink andesite ranges between 2.17-2.34 while grey andesite ranges between 1.31-1.33 respectively (Table 4.19).

Table 4.19 Anisotropy classification according to uniaxial compressive strength

Rock type	Saturated	Dry	Mean
Pink andesite	2.34	2.17	2.14
Grey andesite	1.33	1.31	1.32

Based on Singh et al., (1989) and Ramamurthy (1993) uniaxial compressive strength anisotropy classification, pink andesite is classified as “moderately anisotropic” and grey andesite is “fairly anisotropic” (Table 4.20).

Table 4.20 Strength anisotropy classification after Singh et al.,(1989) and Ramamurthy, *(1993)*

Degree of strength anisotropy ratio, Rc	Description
1.0 - 1.1	Isotropic
1.1 – 2.0	Fairly anisotropic
2.0 – 4.0	Moderately anisotropic
4.0 – 6.0	Highly anisotropic
> 6.0	Very highly anisotropic

4.4.1.3 Relationship between Uniaxial compressive strength and porosity

In this study it is observed that the saturated specimens had a relatively lower strength compared to the dry state specimens, hence the relationship between porosity and uniaxial compressive strength is analyzed. A strong inverse regression was existing between the two properties for both rock types. The graphs and the equation presenting the relationship is shown below.

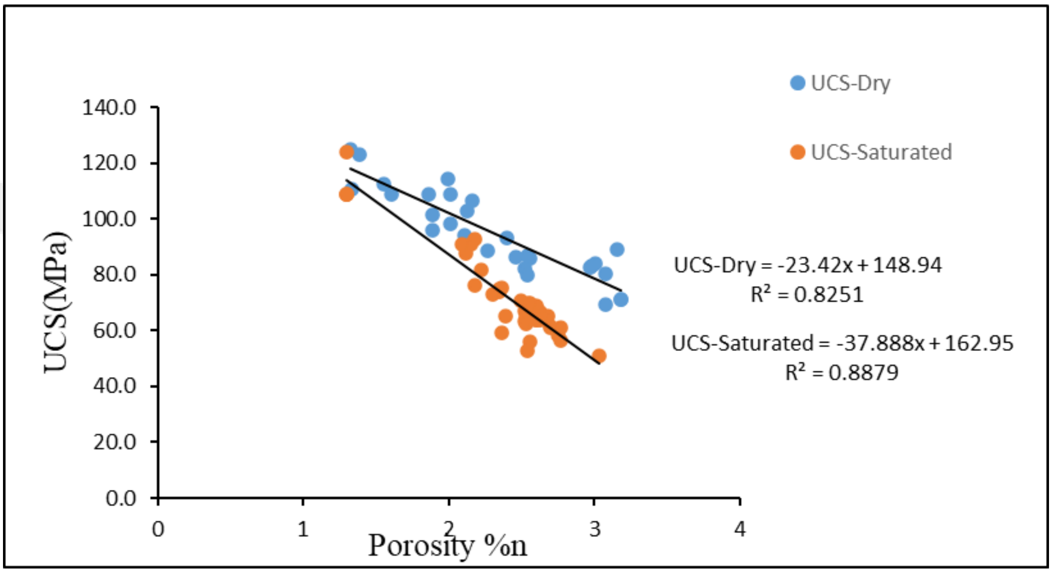

Figure 4.11 Relationship representation of porosity and UCS (grey andesite)

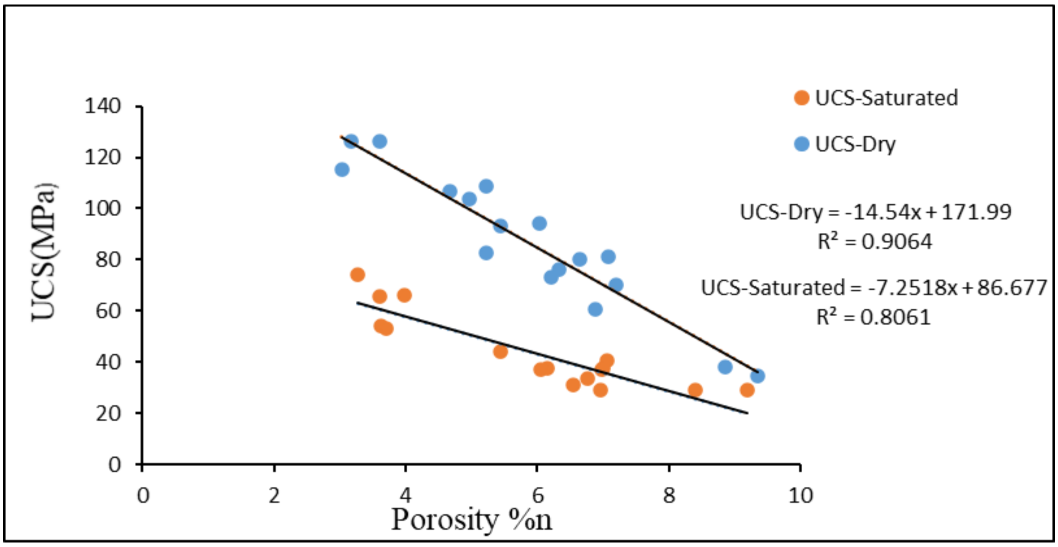

Figure 4.12. Relationship representation of porosity and UCS (Pink andesite)

4.4.2 Brazilian Tensile Strength Test

The indirect uniaxial tensile strength test also referred to as Brazilian tensile strength test. The objective of the test is to measure the uniaxial tensile strength of rock samples indirectly using Brazilian test (ISRM, 1978). Most rocks fail in tension in biaxial stress fields at uniaxial tensile strength that is when the principle stress is tensile and the other finite principal stress is compressive whose magnitude doesn't exceed that of the tensile by 3 times hence the need of Brazilian tensile test (ISRM, 1978). In addition the parameter is an input in determining the anisotropy strength index, which is obtained from the ratio of the maximum and minimum tensile strength($\sigma t_{max}/\sigma t_{min}$) of the rock (Ramamurthy, 1993). Brazilian discs were prepared according to ISRM standards (ISRM, 1978). To assess the effect of anisotropy on the tensile strength of the rock, the disc samples were prepared in respective to the anisotropy plane orientation β= 0°,45° and 90°. The load is applied perpendicular to the diameter center of the disc. The indirect tensile strength is calculated using the following formula (ISRM, 1978);

$$\sigma t = \frac{2P}{\pi Dh} (\mathrm{MPa}) \tag{4.16}$$

Where P is the maximum load applied on specimen after failure (N); the surface area of a cylinder where D and h are the diameter (mm) and thickness (mm) of the specimen.

In order to evaluate the intensity of anisotropy exhibited by the rocks using Brazilian test, the anisotropy index (AI) is defined. Thus, the ratio of the maximum Brazilian test strength and the minimum Brazilian test strength Singh et al. (1989) it is expressed as follows:

$$AI = \frac{\sigma t_{max}}{\sigma t_{min}} \tag{4.17}$$

Where:

σt_{max} is the maximum Brazilian test strength

σt_{min} is the minimum Brazilian test strength

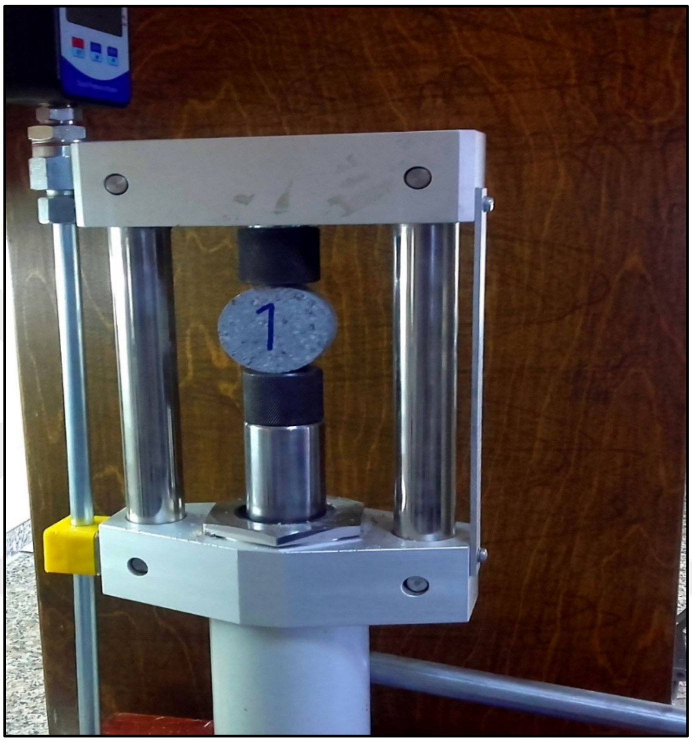

Figure 4.13 Indirect tensile strength (Brazilian) machine (Personal archive,2019)

Table 4.21 Mean Brazilian tensile strength values of grey and pink andesite

Rock type	N	Saturated Brazilian tensile strength (MPa)± Standard deviation	N	Dry Brazilian tensile strength (MPa) ± Standard deviation
Pink andesite	9	3.81 ± 0.34	9	5.03 ± 0.62
Grey andesite	10	7.24 ± 0.93	10	9.10 ± 1.02

Table (4.21) presents results of pink and grey andesite obtained from the Brazilian tensile strength test in function of specimen's physical state. The values recorded in pink andesite are 3.81 ± 0.34 MPa for saturated samples and 5.03 ± 0.62 MPa for dry samples respectively. While in grey andesite, 7.24 ± 0.93 MPa for saturated samples and 9.10 ± 1.02 MPa for dry samples respectively were recorded.

The anisotropy of Brazilian tensile strength the maximum and minimum failure strengths indicated by pink and grey andesite are compared. The maximum strength in grey andesite was indicated at inclination angle β = 90° with values 9.71 ± 0.97 MPa for dry samples and 7.75 ± 0.32 MPa for saturated samples respectively while, the minimum strength was recorded at angle β = 45° for saturated and dry samples values recorded are 6.05 ±028 MPa and 7.95± 0.09 MPa respectively (Table 4.22). Equally in pink andesite the maximum strength was recorded at inclination angle β = 90° with values 5.80 ± 0.07 MPa for dry samples and 4.17 ± 0.32 MPa for saturated samples while the minimum strength while the minimum strength values 4.30 ± 0.05 MPa for dry samples and 3.40 ± 0.06 MPa for saturated samples respectively (Table 4.23).

The tendencies of Brazilian tensile strength recorded at inclination angle of β = 0°, 45° and 90° of pink and grey andesite are shown in Figure 4.14 and 4.16. The variations of Brazilian tensile strength at different inclination angles reveal that the maximum and minimum values presented have a minor difference in both rock types.

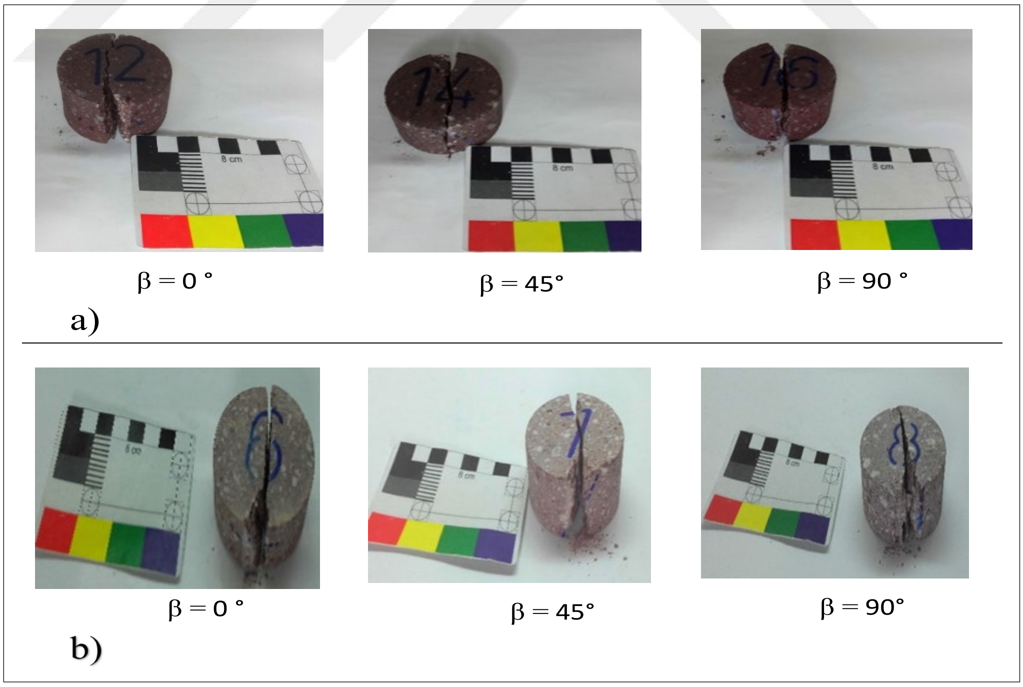

Figure 4.14 Brazilian tensile strength specimens of pink andesite after test at respective angles (a) saturated state (b) dry state (Personal archive,2019)

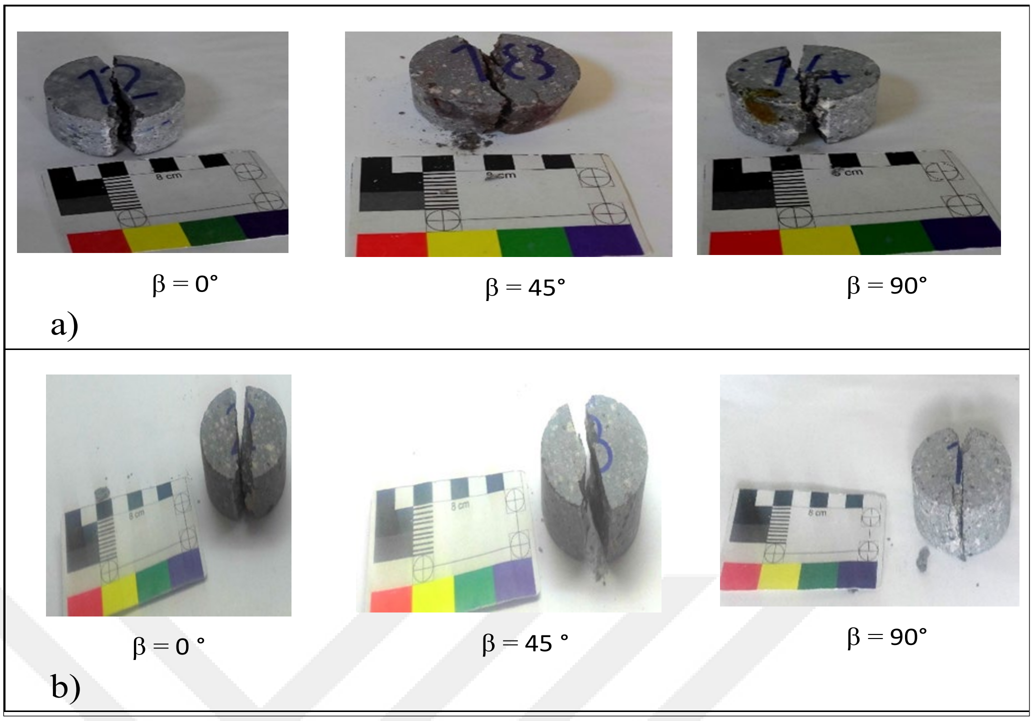

Figure 4.15 Grey andesite Brazilian tensile strength specimens after test at respective angles (a) saturated state (b)dry state (Personal archive,2019)

Table 4.22 Average values of Brazilian tensile strength (MPa) at different inclination angles (grey andesite)

Anisotropy angle (°)	Dry Brazilian tensile strength (MPa)			Saturated Brazilian tensile strength (MPa)		
	N	Mean	± STD	N	Mean	± STD
0	3	9.45	0.51	3	7.29	0.55
45	3	7.95	0.09	3	6.05	0.28
90	3	9.71	0.97	3	7.75	0.32

Table 4.23 Average values of Brazilian tensile strength (MPa) at different inclination angle (pink andesite)

Anisotropy angle (°)	Dry Brazilian test strength (MPa)			Saturated Brazilian test strength (MPa)		
	N	Mean	±STD	N	Mean	± STD
0	3	5.00	0.16	3	3.83	0.03
45	3	4.30	0.05	3	3.40	0.06
90	3	5.80	0.07	3	4.17	0.32

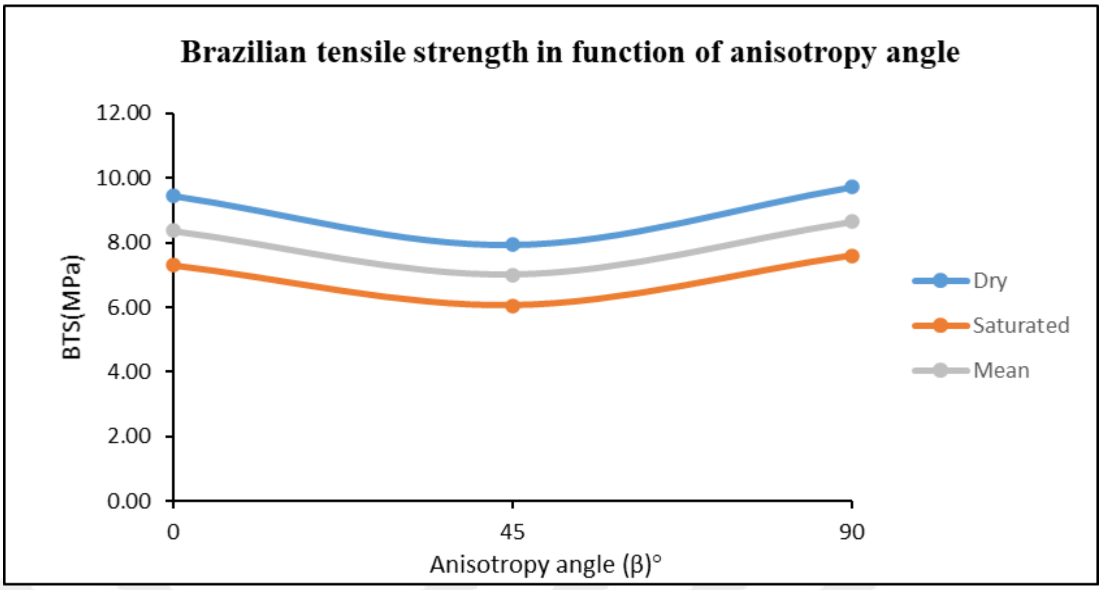

Figure 4.16 Brazilian Tensile Strength (BTS) of Grey Andesite at different angle orientations with average demonstrating the trend of BTS in function of inclination angle

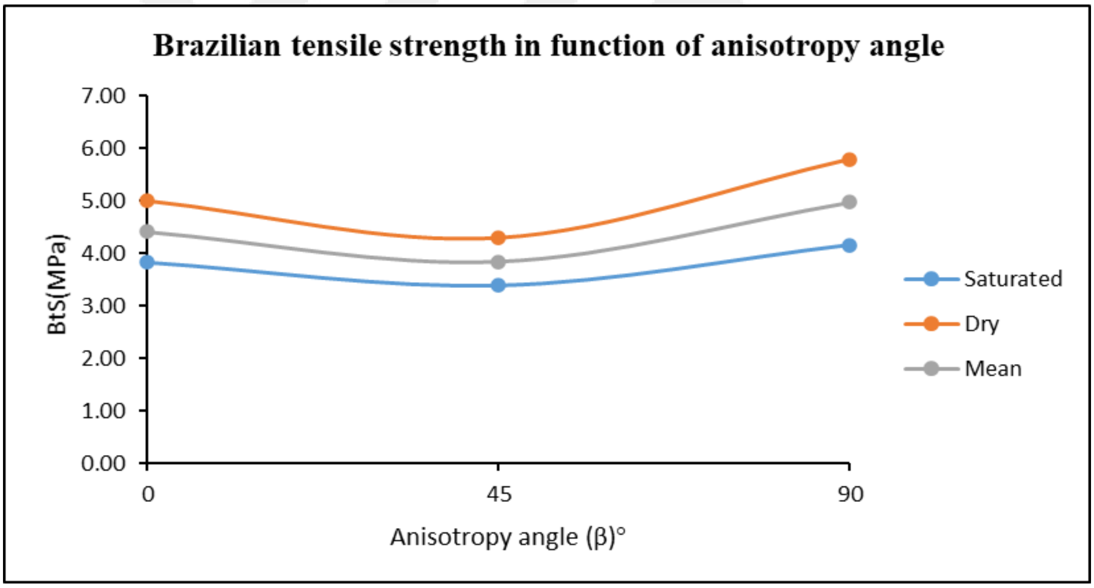

Figure 4.17 Brazilian Tensile Strength (BTS) of Pink Andesite at different angle orientations with average demonstrating the trend of BTS in function of inclination angle

The degree of anisotropy of the established anisotropy index ratios of pink andesite is between 1.23-1.35 while in grey andesite 1.22-1.28 (Table 4.24). Based on the indexes the intensity of anisotropy presented by Brazilian tensile strength in pink and grey andesite is classified as “weak” Singh et al (1989).

Table 4.24 Anisotropic index and classification of pink and grey andesite

Rock type	Anisotropic index (BTS_{max}/BTS_{min})		Degree of anisotropy classification
	saturated	dry	
Pink andesite	1.23	1.35	Weak Anisotropy
Grey andesite	1.22	1.28	Weak Anisotropy

4.4.3 Point load index test

The point load strength test is a mechanical test deliberated to determine the point load strength index ($Is_{(50)}$) of a rock. It is an index test mainly intended to classify the rock strength (ISRM, 1985). The index test is one of simplest rock strength determinant tests in that it can be used in the field because it's portable and requires little or no sample preparation specifications compared to uniaxial compressive strength test. However, the point load results are not to be used in design analysis. The point load index test also determines the point load anisotropy strength index ($Ia_{(50)}$). To determine the point load strength index with interest to the anisotropy exhibited by the rock, axial loading was applied on the samples. To determine the anisotropy exhibited by the rock specimens, cores were drilled parallel and perpendicular to the flow or cooling joint direction. In the study the test was applied on cylindrical cores with a length to diameter ratio of 1-1.5 and a diameter of approximately 54 mm (ISRM 1985). For this study the test was applied on 8 saturated and 8 dry samples 16 in total for each rock type. The samples were subjected to axial loading respecting the anisotropy planes, increasing load was applied until failure occurred. The uncorrected point load strength index (Is) is calculated using the formula;

$$\mathrm{Is} = \frac{\mathrm{P}}{\mathrm{De}^2} \tag{4.18}$$

$$De^2 = \frac{4A}{\pi} \tag{4.19}$$

Is: is the point load strength (MPa)

P: is the maximum applied load (kN) until failure,

De^2: is the equivalent core diameter

The size corrected point load strength, $Is_{(50)}$, is calculated from Is, using equivalent core diameter method (Broch, 1983). According to this formula,

$$Is_{50} = F \times Is \tag{4.20}$$

Is_{50}: is the corrected point load strength

F: is the correction factor

The point load strength anisotropy index in denoted by the formula (ISRM, 1985)

$$Ia_{(50)} = \frac{I_{s\,(50)\perp}}{I_{s(50)\parallel}} \tag{4.21}$$

Where;

$Ia_{(50)}$ is the strength anisotropy index

$Is_{(50)} \perp$ is the point load index corrected strength obtained after failure from the perpendicular foliated core (MPa).

$Is_{(50)} \parallel$ is the corrected point load index strength after failure obtained from the parallel foliated core (MPa).

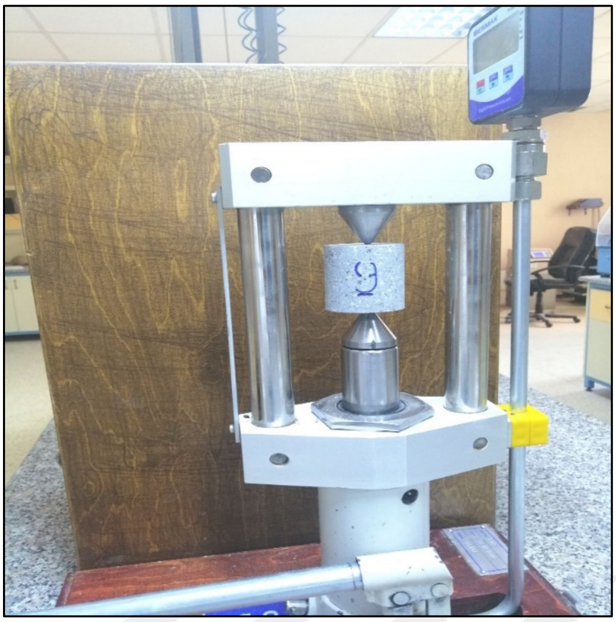

Figure 4.18 Point load index test (Personal archive,2019)

The point load index values were recorded in respective to physical state and their inclination angle. The maximum value in pink andesite was recorded at the normal (90°) 4.89 ± 0.14 MPa and 7.16 ± 0.14 MPa respectively for saturated and dry samples and its minimum values at parallel (0°) with values 4.19 ± 0.06 MPa and 6.32 ± 0.24 MPa respectively for saturated and dry samples (Table 4.26). In grey andesite the maximum value was equally recorded at normal (90°), 6.58 ± 0.14 MPa and 9.82± 0.43 MPa respectively for saturated and dry samples and its minimum values were recorded at the parallel (0°) inclination with values 5.83 ± 0.25 MPa and 7.59 ± 0.69 MPa for the saturated and dry state respectively (Table 4.25).

Table 4.25 Average measurements of Point Load Index at different inclination angle (grey andesite)

Anisotropy Angle (°)	No. of samples	Point load index (MPa)			
		Saturated		Dry	
		Mean	±STD	Mean	±STD
Normal ⊥	8	6.58	0.14	9.82	0.43
Parallel ǁ	8	5.83	0.25	7.59	0.69

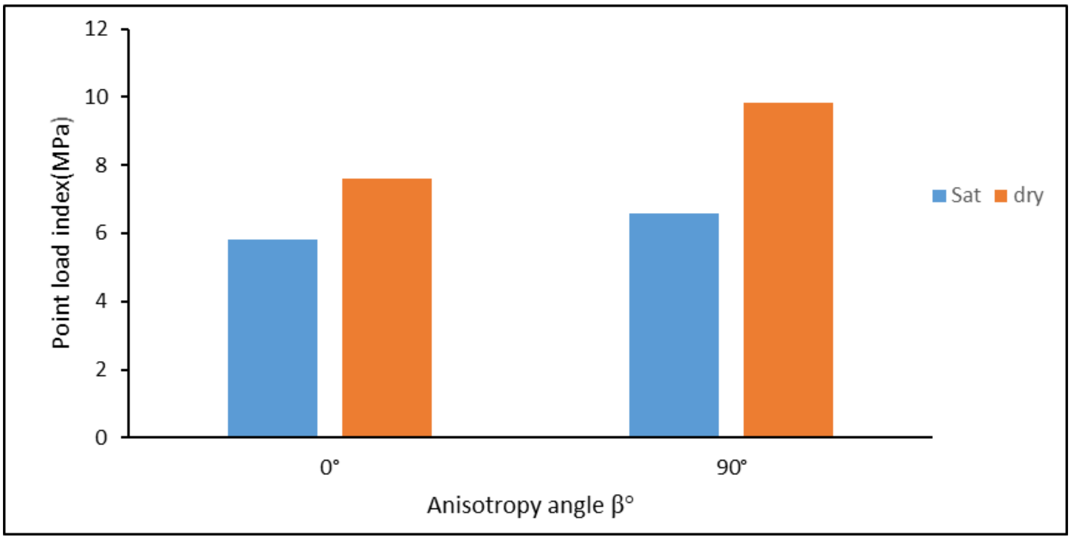

Figure 4.19 Point load index illustration in function of anisotropy angle and physical state in grey andesite

Table 4.26 Mean values of Point Load Index at different inclination angle (pink andesite)

Anisotropy Angle (°)	No. of samples	Point load index (MPa)			
		Saturated		Dry	
		Mean	±STD	Mean	±STD
Normal ⊥	8	4.89	0.14	7.16	0.14
Parallel ǁ	8	4.19	0.06	6.32	0.24

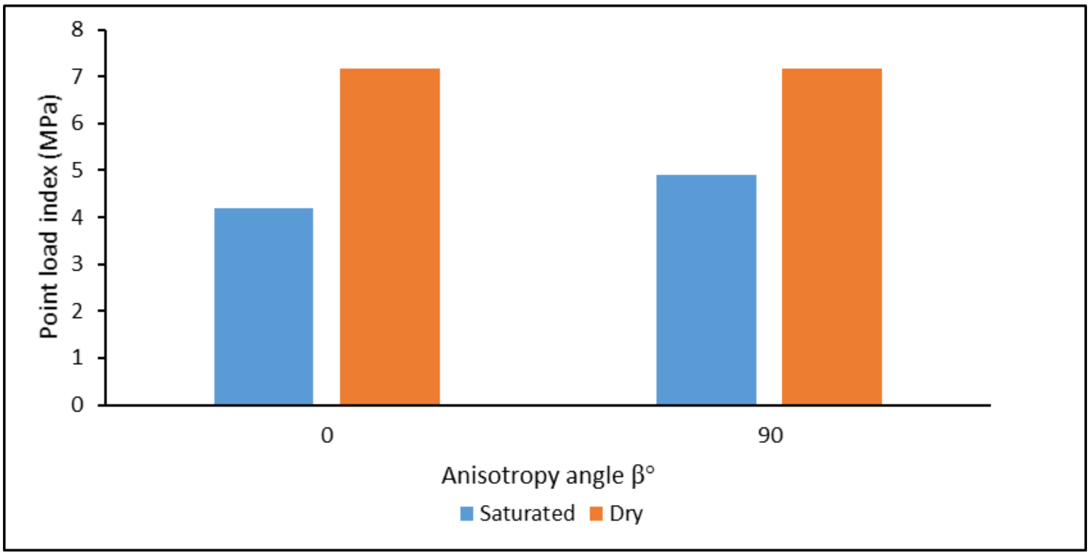

Figure 4.20 Point load index illustration in function of anisotropy angle and physical state in pink andesite

Based on Bieniawski (1975) point load index strength classification pink and grey andesite were classified as "high strength".

Table 4.27 Point load index classification *(Bieniawski, 1975)*

Rock classification	Point load index (MPa)
Very low strength	<1
Low strength	1-2
Moderate strength	2-4
High strength	4-8
Very High strength	>8

4.4.3.1 Degree of Point load index strength anisotropy index Ia (50)

To determine the intensity of strength anisotropy exhibited via point load index test the equation (4.21) was applied. The obtained anisotropy indexes of the rock types are shown in table 4.28, indicated values between 1.13-1.2 respectively for both rock types. Based on the results according to the point load anisotropy index classification both rock types classed as "fairly anisotropic" (Table 4.29).

Table 4.28 Values of point load strength anisotropy index $Ia_{(50)}$

Rock type	Anisotropy index (max/min)		Degree of anisotropy (ISRM, 1985)
	Saturated $I\alpha_{(50)}$	Dry $I\alpha_{(50)}$	
Pink andesite	1.2	1.13	Fairly anisotropic
Grey andesite	1.13	1.2	Fairly anisotropic

Table 4.29 Point load strength anisotropy index classification (ISRM, 1985)

Degree of Point load index strength anisotropy $I\alpha$ (50)	Classification term
1	Isotropic
1-2	Fairly anisotropic
2-4	Highly anisotropic
>4	Very highly anisotropic

4.4.4 Bohme Abrasion Resistance Test

This test is applied in the certification and quality assessment of natural stones the main objective of the test is to determine the abrasion resistance. The test evaluates the wearing resistance of a rock as stated in BS EN 14157 (2004) standard. The abrasion resistance of natural stone is dependent on the mineral composition, macro-micro structural texture of a rock. The test was applied on 70x70x70mm cubes 3 grey and 3 pink andesite respectively. The test was conducted in the rock mechanics laboratory geology engineering department at Dokuz Eylül university using the wide wheel abrasion method. The specimens were subjected to an abrasive load of 294 N. The test was composed of 16 abrasive cycles and each cycle comprises 22 revolutions repeated four times on the same face at a 90° rotation of the specimen.After 16 successive cycles by 4 times ,the weight and volume were measured to the nearest 0.1g and their losses were determined (Table 4.16) using the formula below:

$$\Delta V = \frac{\Delta M}{\rho b} \qquad (4.22)$$

ΔV is the volume loss after 16 cycles in cubic centimetre.
ΔM is (m_i-m_f) the mass loss after 16 cycles in grams.
ρb is the density of the specimen g/cm^3.

Figure 4.21 Bohme abrasion wide wheel machine (Personal archive,2019)

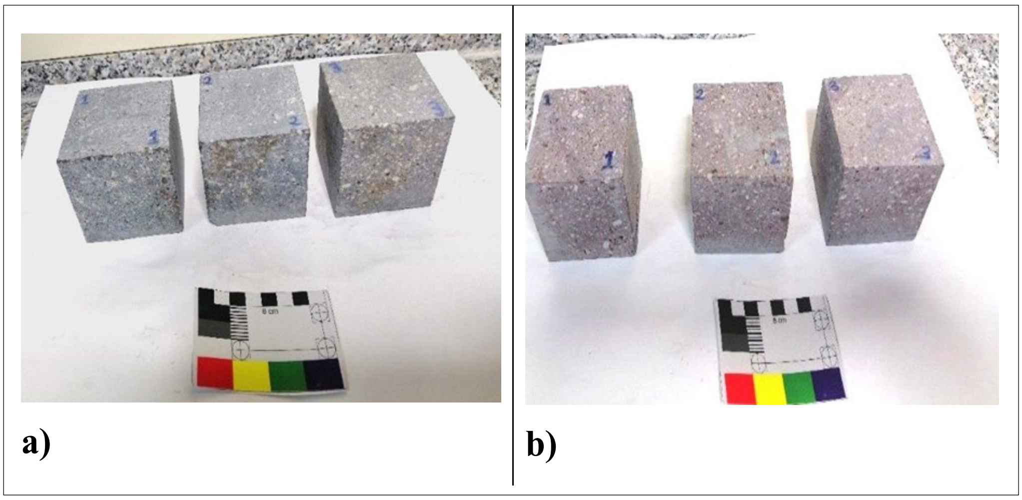

Figure 4.22 Bohme abrasion test specimens(a) grey andesite (b) pink andesite (Personal archive,2019)

The volume loss indicated after the abrasion test is 8.28cm³/50cm² pink andesite and 7.33cm/50cm² in grey andesite respectively (Table 4.30). The volume loss indicated the highest in pink andesite.

Table 4.30 Bohme abrasion resistance volume loss values after test

Rock type	No. of samples	Abrasion surface volume loss $cm^3/50cm^2$	STD (±)
Pink andesite	3	8.28	0.94
Grey andesite	3	7.33	0.72

CHAPTER FIVE
ACCELERATED WEATHERING TESTS

5.1 Wetting and Drying

This accelerated weathering test is used to determine the durability and performance of rock material when subjected to abrasive repeated drying and wetting of the environment. The test was effectuated in accordance to ASTM (2013a). For the wetting and drying test, the samples were submerged in water for 24hrs hours at 15-25°C and then they were dried at 60 -70°C for a minimum of 6hrs.The procedure was repeated 80 times and at every 10^{th} cycle of the procedure the material properties were measured which include unit weight, wave velocity etc. The test was conducted on a total of cylindrical cores. The variations of physical and mechanical properties of the samples are compared to those of the fresh samples. The variations of the physical properties are represented in the properties of the fresh samples are represented by 100% for all the variables.

$$mass\ loss\% = \frac{A - B}{A} \times 100 \tag{5.1}$$

A is the dry mass before the test(gr)
B is the dry mass after the test(gr)

The mass loss percentages values indicated at the completion of 80^{th} cycle of wetting and drying test, were between 0.33% and 0.27%. Grey andesite recorded 0.27% and pink andesite recorded the highest mass loss value with 0.33% (Table 5.1). The mass loss in both rocks demonstrate an exponential and steady increase at every 10^{th} cycle of wetting and drying as shown in Figure.5.3.

Figure 5.1 Wetting and drying pink andesite samples:(A) After completion of test, (B) After uniaxial compressive strength test (Personal archive,2019)

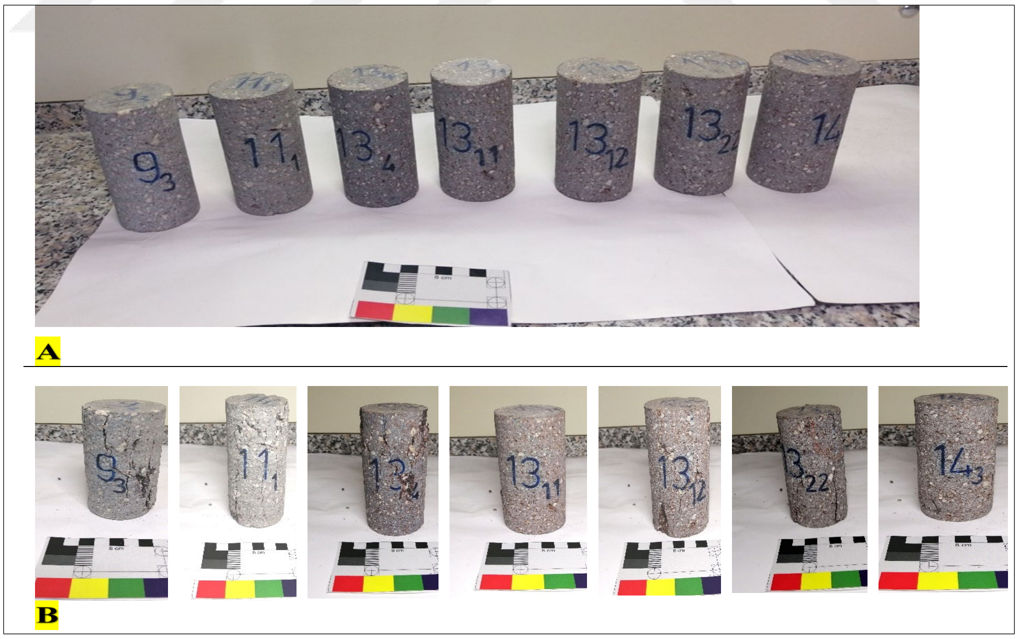

Figure 5.2 Wetting and drying grey andesite samples:(A) After completion of test (B) After uniaxial compressive strength test (Personal archive,2019)

Table 5.1 Average mass loss values after wetting and drying test

Rock Type	N	Mass loss%							
		Number of cycle							
		10	20	30	40	50	60	70	80
Pink Andesite	5	0.03	0.06	0.08	0.10	0.16	0.21	0.30	0.33
Grey Andesite	8	0.02	0.06	0.07	0.09	0.15	0.20	0.25	0.27

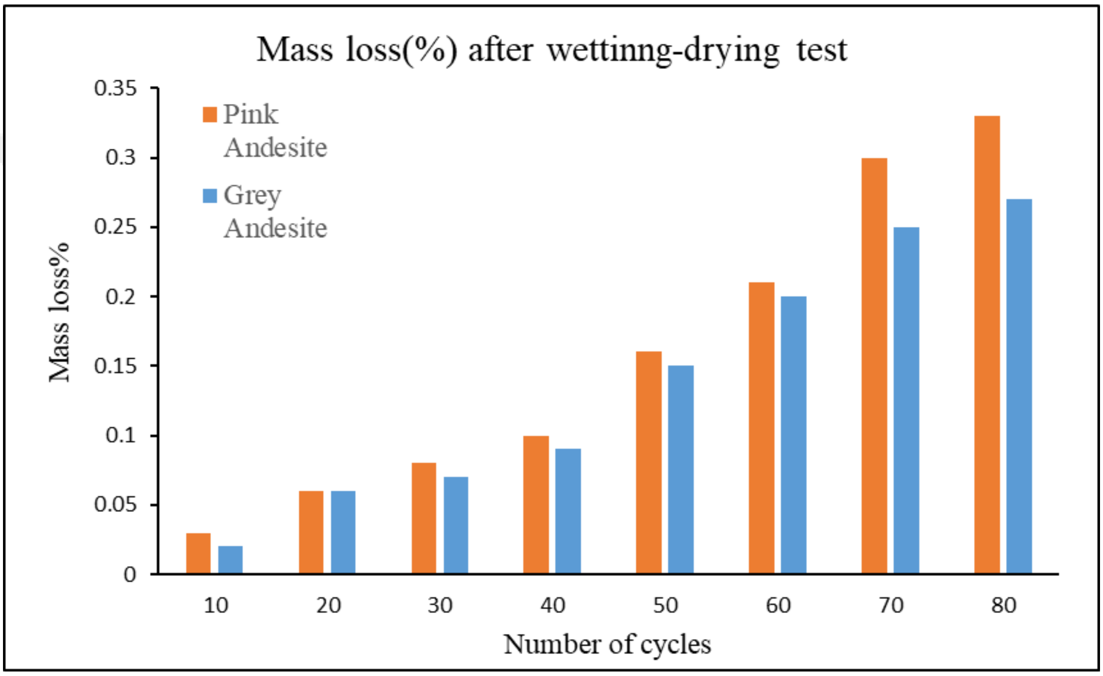

Figure 5.3 Wetting-drying mass loss variation graph

5.1.1 Mechanical properties

Mechanical properties after the wetting and drying accelerated weathering test are evaluated using uniaxial compressive strength test. The rock's uniaxial compressive strength values of the fresh samples and those after completion of the 80th wetting and dry cycle were compared (Figure 5.4). The samples before and after uniaxial compressive strength test are shown in Figure 5.1 and 5.2 respectively.

The uniaxial compressive strength values after the 80th cycle indicated their highest with 83.9 MPa in grey andesite and the lowest 73.61 MPa in pink andesite respectively. The strength in this case maybe influenced by the rate of absorption for each rock type however, there was no notable change in the physical appearance of rock samples.

Table 5.2 Uniaxial compressive strength average values before and after freezing and thawing weathering test

Rock types	Uniaxial compressive strength (MPa), ±Standard deviation	
	Fresh	After wetting and drying
Pink andesite	85.88 ± 28.80	73.61 ± 4.17
Grey andesite	98.95 ± 19.93	83.9 ± 5.40

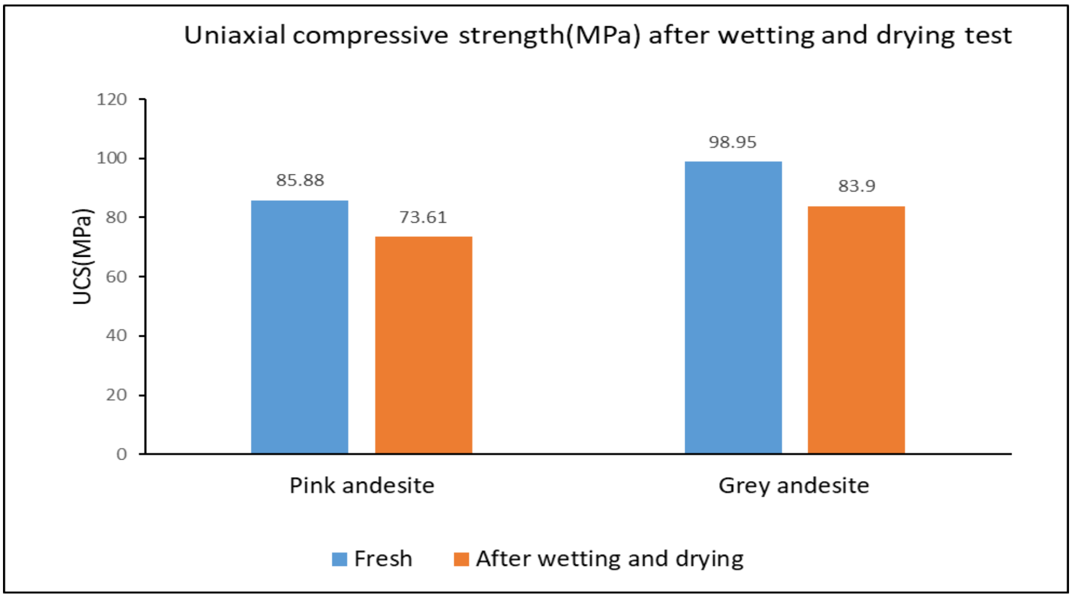

Figure 5.4 Graphical comparison of UCS between fresh and after wetting and drying test

5.1.2 Physical properties after wetting and drying weathering test

The physical properties of wetting and dry accelerated weathering tests were measured at every 10th cycle. The evaluated physical parameters of these samples are dry and saturated unit weight, water absorption under atmospheric pressure, effective porosity, void ratio and P-wave velocity.

The unit weight values after the 80th cycle of wetting and drying for saturated and dry unit weight are 24.60 kN/m³ and 24.26 kN/m³ respectively in grey andesite, 24.13 -23.48 kN/m³ in respectively in pink andesite (Table 5.3 and 5.4). The maximum unit weight indicated was 24.60 kN/m³ in grey andesite while the minimum unit weight was 23.48 kN/m³ in pink andesite respectively. The unit weight average reduction value demonstrated is `0.22% in grey andesite and 0.49% in pink andesite respectively.

The water absorption under atmospheric pressure of the samples, increases exponentially as it attains the 80th cycle of wetting and drying values indicated are 2.75% in pink andesite and 1.41% in grey andesite respectively (Table 5.3 and 5.4).

Effective porosity values indicated in samples after the 80th cycle of wetting and drying activity is 6.59 % in pink andesite, 3.47 % in grey andesite (Table 5.3 and 5.4). A major change in porosity is observed after the 40th cycle in both rock types. The increase rate of rate of porosity after the 80th cycle is 0.99% and 0.64%, in pink and grey andesite respectively. In spite of the increase, the porosity classification remains the same according to Anon (1979) i.e. the porosity of both rock types before the test were classified as pink andesite "medium porosity" while grey andesite "low porosity" respectively.

Notably an increase in void ratio was observed after the 40th cycle for both rock types. An increase in void ratio of 1.12% in pink andesite and 0.64% in grey andesite was indicated. The void ratio values obtained at completion of the 80th cycle is 7.05% in pink andesite with 7.11% and the lowest 3.76% in grey andesite (Table 5.3 and 5.4).

Sonic velocity of both rock types decreases with the increase of cycles. At the end of cycle 20, there is no notable change. However, after the 40th cycle the velocity decreases rapidly. The values indicated for saturated sonic velocity after the 80th cycle is 4976.50m/s in grey andesite 4086.56m/s in pink andesite respectively. The values indicated for dry sonic velocity are 44581.11m/s in grey andesite and 3769.45 m/s in pink andesite (Table 5.3 and 5.4).

Conclusively, the reduction of the saturated and the dry unit weight of pink and grey andesite is very minimal. Thus, the change in the weight of the samples is almost unnoticeable. The water absorption under atmospheric pressure, porosity and void ratio parameters have a significant change after the 40th cycle, the parameters exponentially increase as they attain the 80th cycle in both rock types. In regards to rate of increase and reduction, grey andesite is more resistant to wetting and drying activity than pink andesite. The reduction of saturated and dry sonic velocity gives a similar result in both rock types and physical state, the velocity reduces after the 40th cycle, although the reduction is minor it is quite significant. The variation of all the physical parameters in function of their respective cycle is illustrated as a graph in figure 5.5.

Table 5.3 Wetting-dry average measurements of physical properties of pink andesite

Physical Properties	N	Number of cycles								
		0	10	20	30	40	50	60	70	80
Dry-γ (kN/m³)	5	23.65	23.64	23.63	23.61	23.57	23.55	23.53	23.50	23.48
Sat-γ (kN/m³)	5	24.20	24.20	24.19	24.18	24.15	24.15	24.15	24.14	24.13
Watm (%)	5	2.32	2.35	2.38	2.40	2.47	2.56	2.62	2.72	2.75
Porosity (%n)	5	5.60	5.66	5.73	5.77	5.94	6.13	6.27	6.52	6.59
Void ratio (%e)	5	5.93	6.00	6.08	6.13	6.32	6.54	6.70	6.97	7.05
Dry P-wave m/s	5	3934.61	-	3875.28	-	3869.36	-	3807.67	-	3769.45
Saturated P-wave m/s	5	4359.95	-	4340.69	-	4282.21	-	4169.14	-	4057.65

Table 5.4 Wetting-drying average values of physical properties of grey andesite

	N	Number of cycles								
		0	10	20	30	40	50	60	70	80
Dry-γ (kN/m³)	5	24.35	24.34	24.33	24.33	24.32	24.29	24.28	24.26	24.26
Sat-γ (kN/m³)	5	24.62	24.62	24.62	24.62	24.61	24.60	24.60	24.60	24.60
Watm (%)	5	1.13	1.14	1.18	1.19	1.22	1.28	1.32	1.38	1.41
Porosity (%n)	5	2.81	2.84	2.93	2.96	3.02	3.17	3.28	3.41	3.47
Void ratio (%e)	5	2.89	2.92	3.02	3.05	3.12	3.28	3.39	3.53	3.60
Dry P-wave m/s	5	4841.31	-	4693.93	-	4608.45	-	4598.15	-	4581.11
Saturated P-wave m/s	5	5125.14	-	5113.47	-	5061.71	-	5054.04	-	4976.50

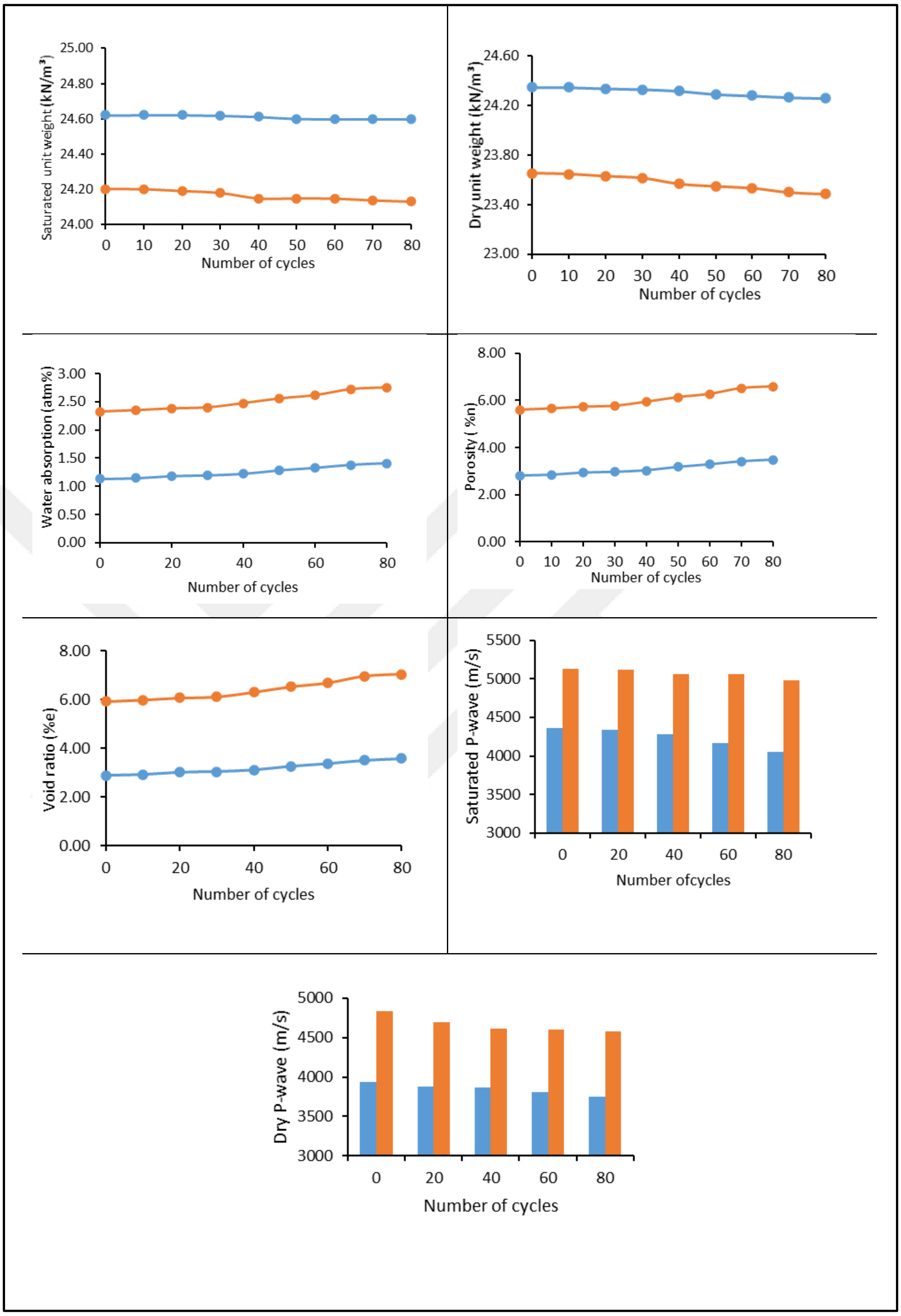

Figure 5.5 Variation of physical properties after wetting and drying accelerated test (blue line and column represent grey andesite; the orange column and line represent pink andesite)

5.2 Freezing & Thawing test

Freezing and thawing test is considerably an interest in engineers, designers, researchers as well as builders that is because it's essential for predicting the stability and performance of rock building material over a time frame under abrasive environmental conditions. The formation of ice crystals during freezing-thawing, generate stresses that affect the physical and mechanical properties of rock significantly. The effects are obtained by varying temperature below and above 0°C on samples containing a known amount of water. To get significantly accurate results freezing and thawing test are to be conducted on rocks with an absorption under pressure value greater than 1% according to Clark (1988) or rather greater than 0.5% according to CIRIA/CUR (1991). In this study the test was conducted on 16 cylindrical cores samples for each rock type according to ASTM (1992). The samples were subjected to 6hrs of freezing under -20° in a freezing cabinet they were submerged in water for 12hrs for 45 times. At every fifth of the cycle physical properties measured and the mass loss at the end of every cycle was calculated.

Based on the test results, the overall mass loss upon the completion of the freezing-thawing test of pink and grey andesite is 0.52% and 0.39% respectively (Table 5.5).

Table 5.5 Freezing-thawing mass loss values of pink and grey andesite

Rock type	N	Mass loss%								
		Number of cycles								
		5	10	15	20	25	30	35	40	45
Pink Andesite	8	0.05	0.11	0.16	0.19	0.23	0.27	0.35	0.41	0.49
Grey Andesite	8	0.04	0.06	0.10	0.12	0.14	0.17	0.20	0.24	0.34

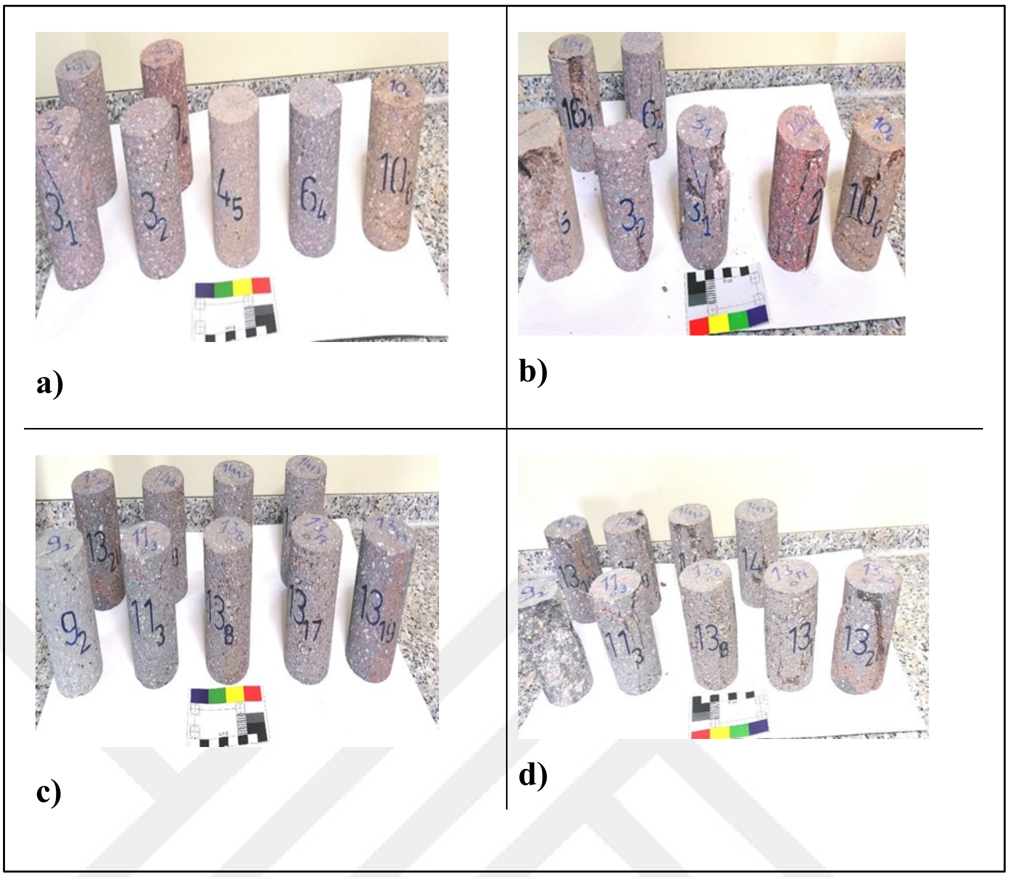

Figure 5.6 Freezing and thawing samples; (a) Pink andesite after completion of 45th cycle (b)Pink andesite after uniaxial compressive strength test, (c) Grey andesite after completion of 45th cycle and (d)Grey andesite after uniaxial compressive strength test (Personal archive,2019)

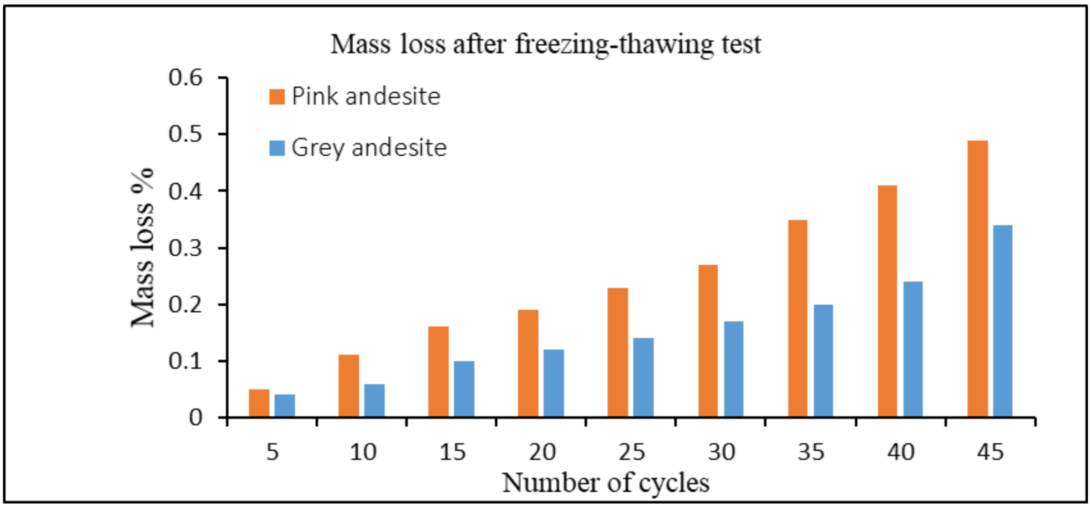

Figure 5.7 Mass loss variations at every cycle after freezing-thawing test of pink and grey andesite

5.2.1 Mechanical properties after freezing and thawing accelerated test

Uniaxial compressive strength values after a 45th cycle of freezing and thawing was used to evaluate the effect of the activity on the rock's strength in comparison to the fresh samples (Table 5.6).

The attained uniaxial compressive strength after the 45th cycle of freezing and thawing ranges between 76.60 and 87.33 MPa (Table 5.6). The maximum value was attained in grey andesite and the minimum in pink andesite. The effect of freezing and thawing activity on the rock's strength is insignificant that their strength classification is constant "high strength" as that of the fresh samples according to ISRM (1981).

Table 5.6 Uniaxial compressive strength mean values before and after freezing and thawing test

Rock type	Uniaxial compressive strength (MPa)	
	Fresh	After freezing and thawing test
Pink andesite	85.88 ± 28.80	76.60 ± 3.49
Grey andesite	98.95 ± 19.93	87.33 ± 10.88

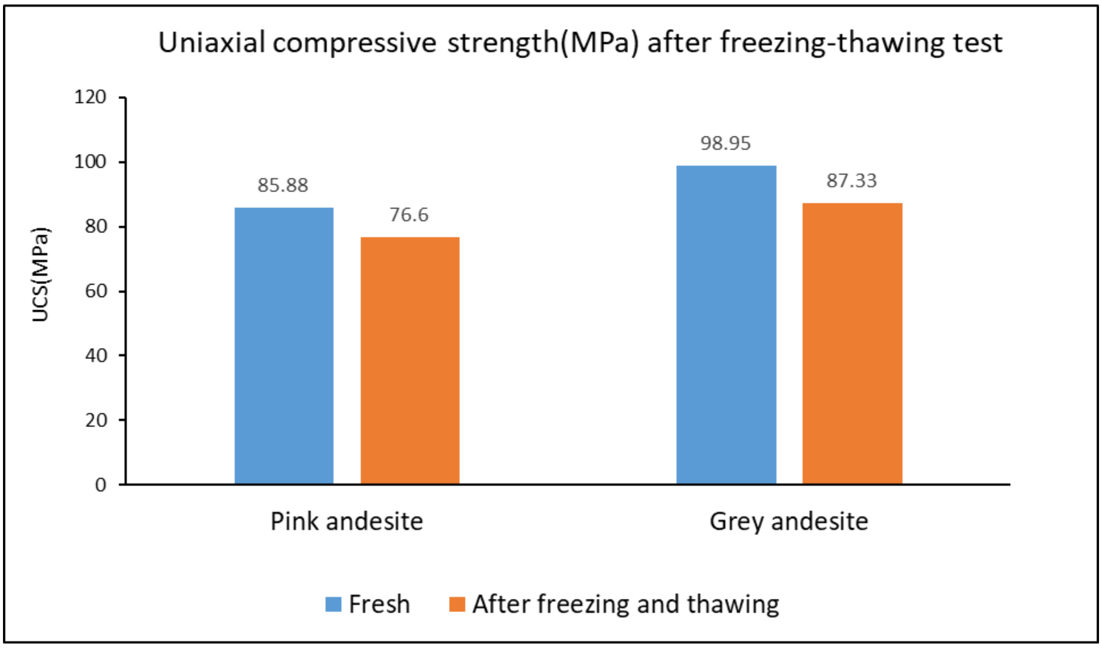

Figure 5.8 Graphic comparison of uniaxial compressive strength before and after freezing-thawing activity

5.2.2 Physical properties after freezing and thawing weathering test

After the completion of 45 cycles of freezing and thawing activity that the samples were subjected to, the physical parameters of the samples were measured at every 5th day of each cycle. The physical parameters evaluated include dry and saturated unit weight, water absorption under atmospheric pressure, porosity, void ratio, saturated and dry sonic velocity. The results obtained are represented at every 5th cycle in table 5.7 and 5.8.

The acquired saturated and dry unit weight values after freezing and thawing activity are 24.41 and 23.96 kN/m^3 in grey andesite respectively, 24.24 and 23.58 kN/m^3 in pink andesite respectively. A minor reduction of unit weight in both rock type is observed. The mean reduction values indicated are 0.51% in grey andesite,0.78% in pink andesite. The changes in unit weight are minor and insignificant as it almost remains unchanged in both rock types as demonstrated graphically in Figure 5.6.

The water absorption under atmospheric pressure of the samples increases steadily from the fifth cycle until the 45th cycle. The water absorption values range between 2.75 and 1.89% for all the samples (Table 5.7 and 5.8). The maximum water absorption was recorded is 2.75 % in pink andesite while minimum value 1.89%in grey andesite. Indicating an increase of 0.63% for pink andesite and 0.37% for grey andesite respectively.

The effective porosity of the samples after the 45th cycle of freezing and thawing is between 7.13 and 4.58 % (Table 5.7 and 5.8). It is observed that effective porosity increases exponentially until the completion of the test is observed after the test. Pink andesite indicated the highest porosity value with 7.13% and lowest 4.58% in grey andesite. The increase rate of porosity after the 45th cycle is 0.88% and 1.48 % in pink and grey andesite respectively. In spite of a reliable significant change in porosity, the classification remains the same according to Anon (1979), i.e. the porosity of both rock types before the test were classified as “medium porosity” in pink andesite ,“low porosity” in grey andesite respectively.

The void ratio increases steadily in all samples. However, the change in void ratio is major after the 35th cycle in both rock types. Notably the increase rate of void ratio after freezing and thawing is 1.71% in pink andesite and 0.97% in grey andesite was indicated. The maximum void ratio value was recorded after the 45th cycle is indicated in pink andesite with 7.13% and the minimum 4.82% in grey andesite (Table 5.7 and 5.8).

The saturated and dry sonic velocity of all the samples decreases with the increase of cycles. The values indicated after the 45th cycle is 4570.93 m/s in grey andesite and 4429.25 m/s in pink andesite for saturated sonic velocity. The values indicated for dry sonic velocity are 4486.73 m/s in grey andesite and 4272.11 m/s in pink andesite (Table 5.7 and 5.8). The change is minor but significant in dry sample than in saturated samples as shown in Figure.5.6.

Conclusively, the reduction of the saturated and the dry unit weight in grey andesite is almost unnoticed while the change in pink andesite is significant. The water absorption under atmospheric pressure, porosity and void ratio parameters exhibit quite a significant change at all the cycles. However, the change is rather not consistent but it varies at different cycles. The parameters exponentially increase as they attain the 45th cycle of freezing and thawing. In regards to rate of increase grey andesite is more resistant to freezing-thawing activity than pink andesite. The reduction of sonic velocity in saturated samples is very minor that the change is almost unnoticeable. Whereas, the reduction of sonic velocity in dry sample is considerable. The variation of all the physical parameters in function of their respective cycle is illustrated as a graph in Figure 5.9.

Table 5.7 Average values of physical properties freezing-thawing of pink andesite

Physical properties	N	Number of cycles									
		0	5	10	15	20	25	30	35	40	45
Dry-γ (kN/m³)	7	23.85	23.86	23.82	23.77	23.75	23.71	23.68	23.64	23.62	23.58
Sat-γ (kN/m³)	7	24.35	24.35	24.34	24.30	24.29	24.26	24.26	24.24	24.23	24.24
Watm (%)	7	2.12	2.07	2.15	2.22	2.28	2.33	2.44	2.54	2.54	2.75
Porosity (%n)	7	5.13	5.02	5.23	5.38	5.53	5.64	5.91	6.13	6.13	6.61
Void ratio (%e)	7	5.43	5.31	5.54	5.72	5.88	6.00	6.31	6.55	6.57	7.13
Dry P-wave m/s	7	4435.13	-	-	4435.13	-	-	4306.54	-	-	4272.11
Saturated P-wave m/s	7	4541.14	-	-	4541.14		-	4441.54	-		4429.25

Table 5.8 Mean values of physical properties after freezing-thawing test of grey andesite

Physical propertis	N	Number of cycles									
		0	5	10	15	20	25	30	35	40	45
Dry-γ (kN/m³)	8	24.13	24.13	24.10	24.07	24.05	24.05	24.02	24.00	23.98	23.96
Sat-γ (kN/m³)	8	24.50	24.50	24.49	24.46	24.45	24.45	24.42	24.43	24.42	24.41
Watm (%)	8	1.52	1.53	1.62	1.64	1.64	1.66	1.68	1.80	1.86	1.89
Porosity (%n)	8	3.70	3.75	3.96	4.01	4.02	4.06	4.10	4.40	4.53	4.58
Void ratio (%e)	8	3.85	3.90	4.13	4.18	4.19	4.23	4.28	4.61	4.75	4.82
Dry P-wave m/s	8	4521.49	-	-	4534.77	-	-	4503.77	-	-	4486.73
Saturated P-wave m/s	8	4590.31	-	-	4622.36	-	-	4582.80	-	-	4570.94

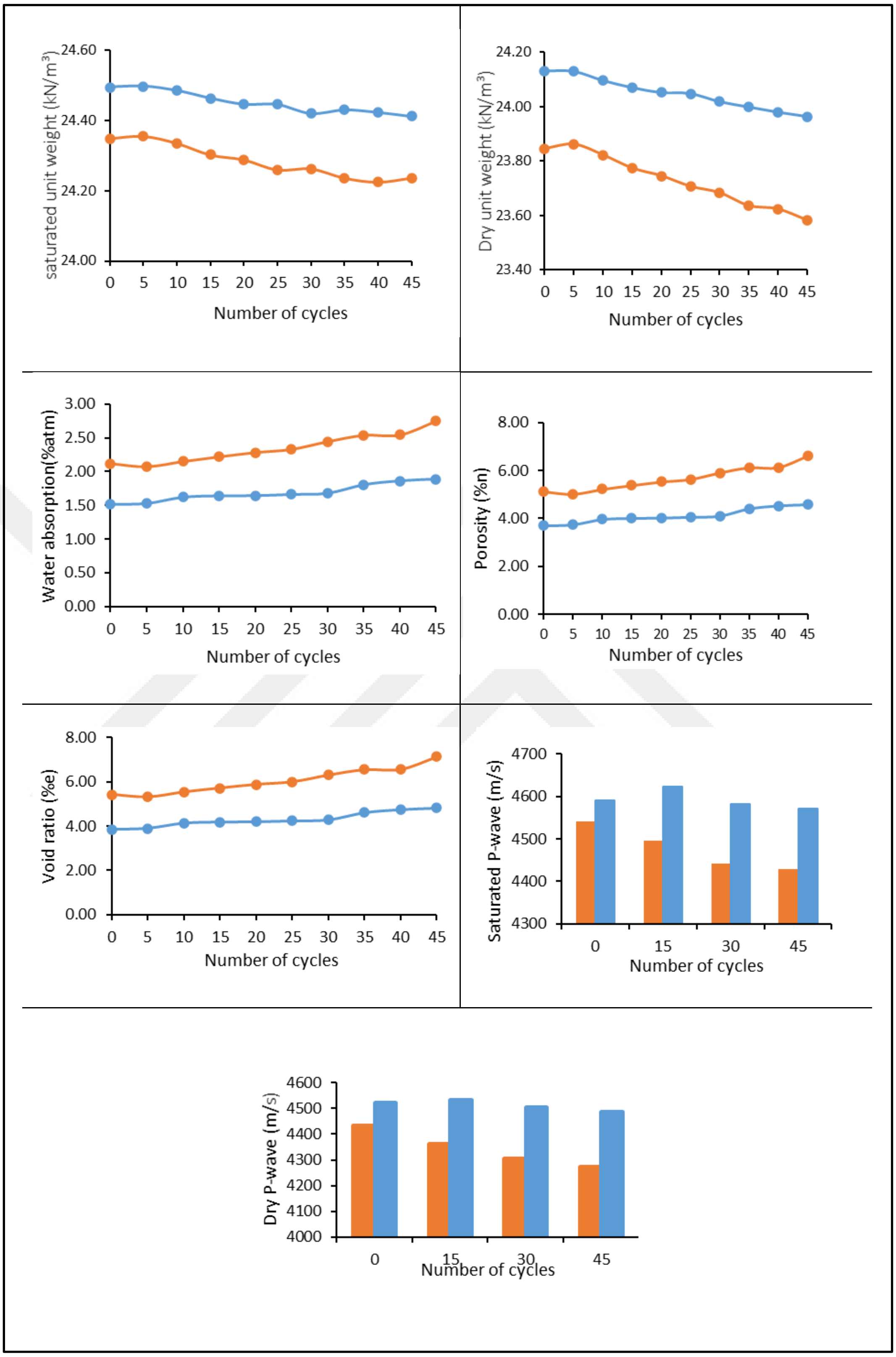

Figure 5.9 Variation of physical properties after freezing and thawing accelerated weathering test (the blue line and column represent grey andesite; the orange line and column represent pink andesite)

5.3 Salt crystallization soundness test

Salt crystallization is one of the most aggressive weathering conditions that affect the stability of rock material compared to physical weathering**.** The salt crystallization test attempts to reproduce the effects of salt crystallization occurring under harsh environmental conditions (RILEM, 1980; Yavuz & Topal, 2007). In this study Na_2SO_4 and $MgSO_4$ salt crystallization soundness test was performed on fresh andesite core samples.

5.3.1 Magnesium Sulphate ($MgSO_4$) soundness test

The magnesium sulphate ($MgSO_4$) soundness test is used as a qualitative input when evaluating the soundness of a rock that has been subjected to weathering action. The objective of the test is to measure physical break down caused by the formation of salt crystals in the pores of rock samples.16 core samples 8 pink and 8 grey respectively, were immersed in salt solution of 1500g $MgSO_4$ per 1liter of distilled water for the test. The process creates pressure as the salt crystals grow in course of the immersion, the effect is similar to that of freezing water. The test was applied in accordance to (ASTM D5240, 2013). The samples were immersed in the salt solution for 17 hours then were left in at room temperature for 2hrs thereafter they were dried at 105°C degrees for 24hrs and finally were left at room temperature for 5hrs to mark a complete cycle. The samples percentage mass loss is then measured. The loss of mass is calculated as follows:

$$Mass\ loss_{MgSO4} = \left(\frac{M_1 - M_2}{M_1}\right) \times 100 \qquad (5.2)$$

Where:

M_1 : dry mass before magnesium sulphate soundness test (gr)

M_2: dry mass after magnesium sulphate soundness test (gr)

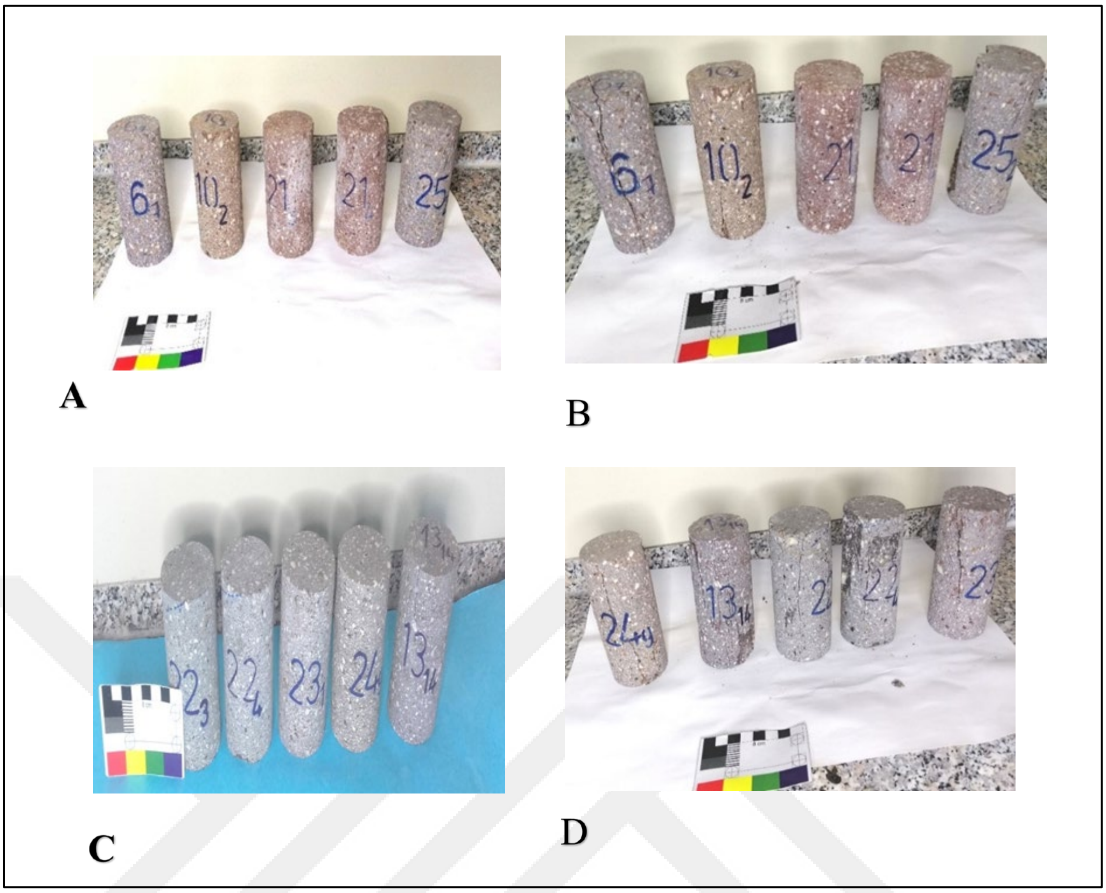

Figure 5.10 Magnesium sulphate salt crystallization samples; (A) Pink andesite after completion of 5th cycle,(B)Pink andesite after uniaxial compressive strength test, (C) Grey andesite after completion of 5th cycle and (D) Grey andesite after uniaxial compressive strength test (Personal archive,2019)

Based on the test results, the mass loss of grey and pink andesite after magnesium sulphate soundness test is 0.49% and 0.41% respectively (Table 5.9).

Table 5.9 Magnesium sulphate soundness mass loss values of the grey and pink andesite

Rock Type	Mass loss%		
	N	Mean	STD(±)
Pink Andesite	5	0.49	0.07
Grey Andesite	5	0.41	0.05

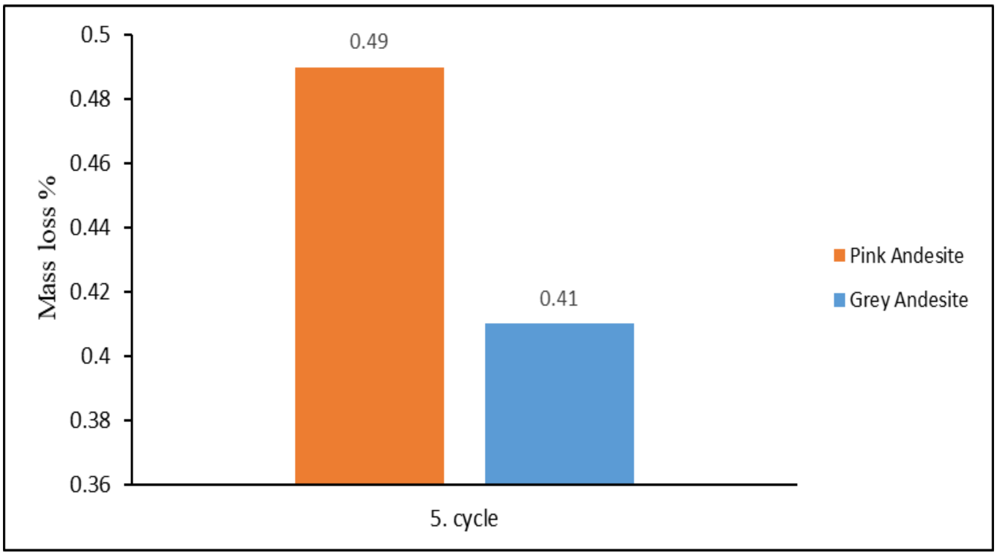

Figure 5.11 Mass loss bar graph of pink and grey andesite after $MgSO_4$ soundness test

The effect of magnesium sulphate soundness test on uniaxial compressive strength of pink and grey andesite is quite significant. The strength of the rock significantly reduces after the 5th cycle of MgSO4. The reduction indicated is 15.66 MPa in pink andesite and 20.67 MPa in grey andesite, the actual strength exhibited 70.22 MPa and 78.28 MPa respectively (Table 5.10). A graph illustrating the reduction of the strength before and after the test is shown in Figure 5.10. Successively the rate of reduction is likely to increase with the increase of cycles.

Table 5.10 Uniaxial compressive strength values after Magnesium Sulphate soundness test of pink and grey andesite

Rock type	Uniaxial compressive strength (MPa)± S. D	
	Fresh specimen	After $MgSO_4$
Pink andesite	85.88 ± 28.80	70.22 ± 1.90
Grey andesite	98.95 ± 19.93	78.28 ± 2.34

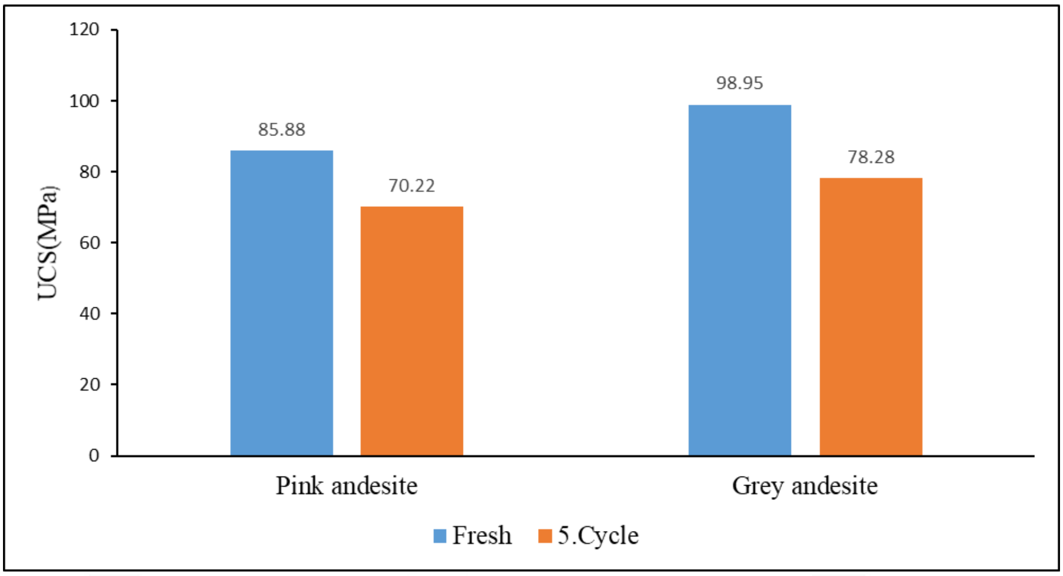

Figure 5.12 Uniaxial compressive strength (MPa) after magnesium sulphate soundness test of pink and grey andesite

The physical properties evaluated after a total completion of the magnesium sulphate soundness test include dry and saturated unit weight, effective porosity, water absorption under atmospheric pressure, void ratio, dry and saturated sonic velocity. The results obtained were compared to the physical parameters before the test.

The unit weight after the test of saturated and dry unit weight values 23.91 and 23.60 kN/m³ in grey andesite, 23.59 and 22.59 kN/m³ in pink andesite respectively respectively for all the samples (Table 5.10 and 5.11). The change in unit weight after the test is varies in function of the rock type and the physical states. Pink andesite exhibited a higher density loss in its saturated and dry state with values 1.45 and 1.83% respectively. Whereas grey andesite exhibited a lower density reduction with values 0.60% and 0.93% in its saturated and dry state respectively.

Water absorption under atmospheric pressure of pink and grey andesite increased by 0.40% and 0.24% respectively after a total completion $MgSO_4$ soundness test. Bringing the actual value to 2.72% in pink andesite and 1.36% in grey andesite (Table 5.10 and 5.11).

Effective porosity of pink and grey andesite increased by 0.8% and 0.6% respectively. The actual porosity values obtained are 6.4% in pink andesite and 3.3% in grey andesite (table 5.10 & 5.11). In spite of the increase in porosity, the classification based on Anon (1979) remains unchanged. That is pink andesite is classified as "medium porosity" while grey andesite "low porosity".

The void ratio of pink and grey andesite after the completion of $MgSO_4$ soundness test increased by 0.95% in pink andesite and 0.60% in grey andesite respectively. The actual values of void ratio increase to 6.83% in pink andesite and 3.39% in grey andesite. In relation to the rate of increase pink andesite more affected by $MgSO_4$ salt crystallisation than grey andesite.

The sonic velocity of pink and grey andesite indicated a decrease after the completion of $MgSO_4$ soundness test. The change in sonic velocity after the test was more pronounced in pink andesite for saturated and dry samples, indicating 4575 m/s and 4117 m/s respectively (Table 5.11). While the change is grey andesites is minor or almost unchanged for saturated and dry sample, indicating 5154 m/s and 5038 m/s respectively (Table 5.12).

In conclusion there wasn't any physical disintegration of any of the samples. The reduction of saturated and dry unit weight after the test is not significant in grey andesite but is important in pink andesite. The increase of water absorption under atmospheric pressure, effective porosity and void ratio is quite significant but the rock's classification remains unchanged. The saturated and dry sonic velocity decrease after the test, the velocity of pink andesite is affected by the salt crystallisation than grey andesite. Generally, the changes of physical and mechanical properties after the $MgSO_4$ soundness test are minor yet significant. The changes in the physical properties are illustrated in Figure.5.9.

Table 5.11 Physical properties mean values after magnesium sulphate soundness test for pink andesite

Physical properties	N	Number of cycles	
		0	5
Dry unit weight (kN/m³)	5	23.40	22.59
Saturated unit weight (kN/m³)	5	23.95	23.60
Watm (%)	5	2.32	2.72
Effective Porosity (%n)	5	5.5	6.4
Void ratio (%e)	5	5.88	6.83
Dry P-wave velocity (m/s)	5	4397	4117
Saturated P-wave velocity (m/s)	5	4707	4575

Table 5.12 Average measurements of physical properties after magnesium sulphate soundness for grey andesite

Physical properties	N	Number of cycles	
		0	5
Dry unit weight (kN/m³)	5	23.81	23.59
Saturated unit weight (kN/m³)	5	24.08	23.91
Watm (%)	5	1.12	1.36
Effective Porosity (%n)	5	2.7	3.3
Void ratio (%e)	5	2.79	3.39
Dry P-wave velocity m/s	5	5044	5038
Saturated P-wave velocity (m/s)	5	5209	5154

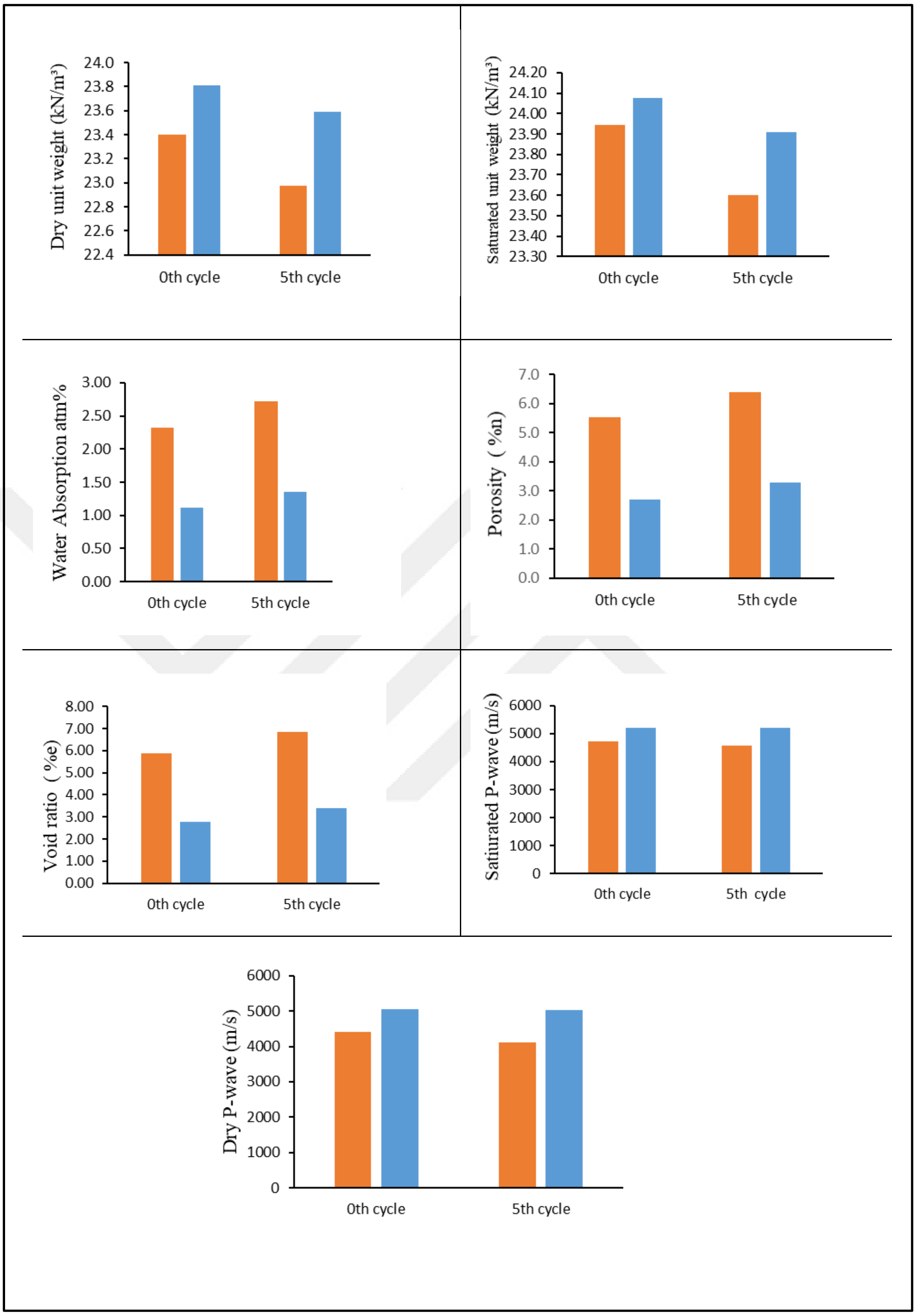

Figure 5.13 Variation of physical properties after magnesium sulphate ($MgSO_4$) soundness test (blue bar shows the grey andesite and orange bar shows pink andesite

5.3.2 *Sodium sulphate (Na_2SO_4) soundness test*

The Sodium Sulphate (Na_2SO_4) soundness test is an accelerated weathering test used to evaluate the resistance of the rock after interjection of salt crystals in the pores of the rock during the cycle. Sodium sulfate (Na_2SO_4) salt crystallization was conducted in accordance to (ASTM D5240, 2013). To prepare the salt solution 86g sodium sulphate was dissolved in 1litre of distilled water. The core specimens were immersed in the salt solution for 2hours then were left to dry at 105 degrees for 16-18hrs there after left at room temperature for 2 hours. The process was repeated for 15 times. The total completion of the process the samples were washed in distilled water to ensure complete removal of salt from the samples. Subsequently the mass loss after the test is calculated. The physical and mechanical properties were assessed and compared to initial parameters of fresh samples.

Based on the test results, the mass loss of grey and pink andesite after the completion of sodium sulphate soundness is 0.68 % and 1.22 % respectively (Table 5.13).

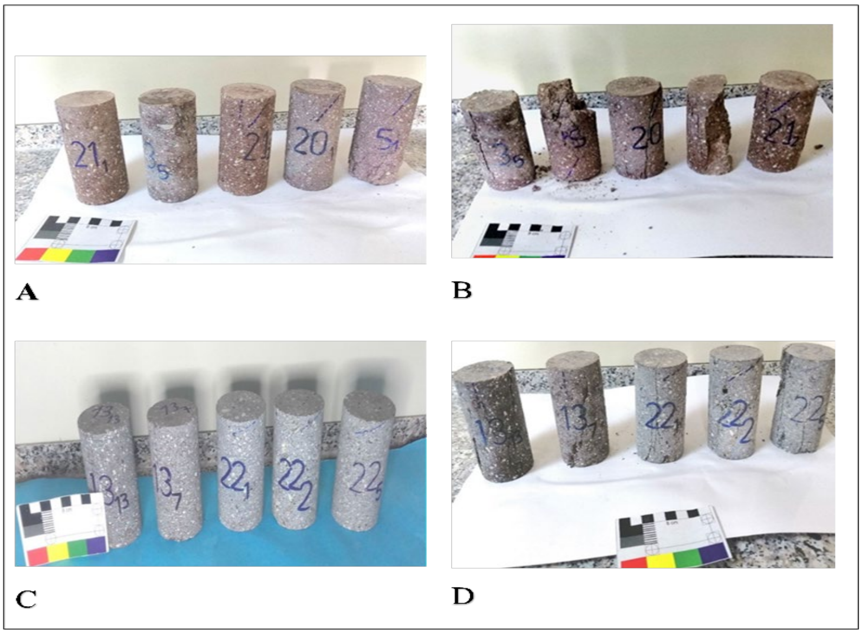

Figure 5.14 Sodium Sulphate salt crystallization samples; (A) Pink andesite after completion of 15th cycle (B) Pink andesite after uniaxial compressive strength test, (C) Grey andesite after completion of 15th cycle and (D) Grey andesite after uniaxial compressive strength test (Personal archive,2019)

Table 5.13 Sodium sulphate (Na_2SO_4) soundness test mass loss

Rock Type	Mass loss %			
	N	Number of cycle		
		5	10	15
Pink andesite	5	0.45	0.94	1.22
Grey andesite	5	0.24	0.54	0.68

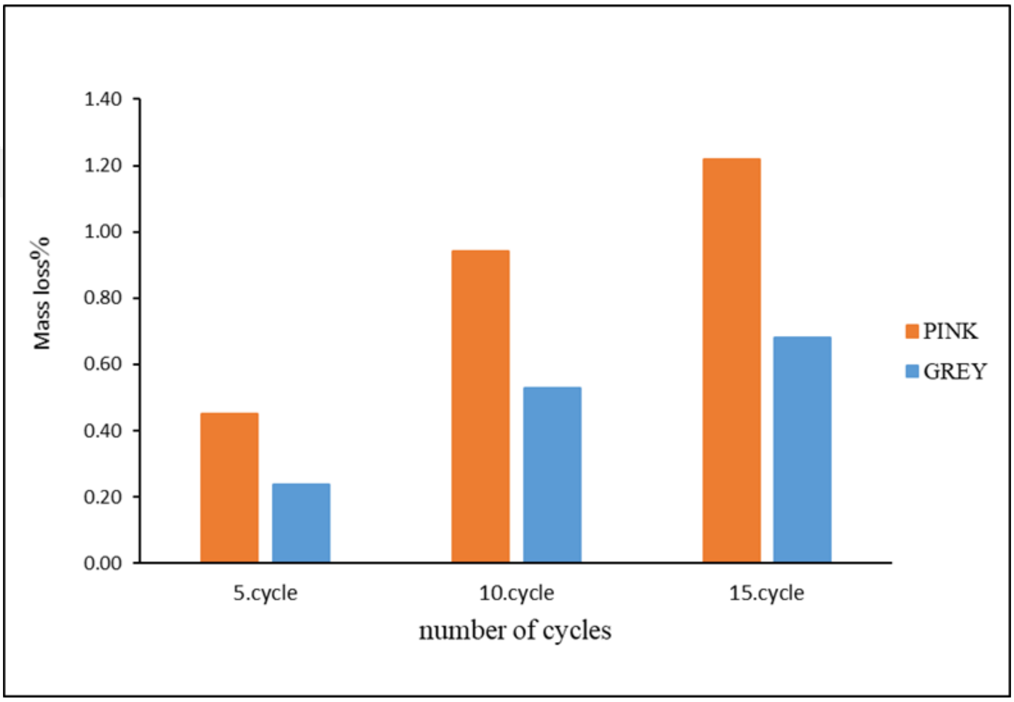

Figure 5.15 Sodium sulphate soundness test mass loss in function of cycles graph illustration

The effect of sodium sulphate soundness test on uniaxial compressive strength of pink and grey andesite is quite significant. The strength of the rock significantly reduces after the 15th cycle of Na_2SO_4.The reduction indicated is 18.03 MPa in pink andesite and 26.1 MPa in grey andesite, the actual strength exhibited is 67.55 MPa and 98.95 Mpa respectively (Table5.14). A graph illustrating of the strength reduction before and after the test is shown in Figure 5.16. Successively the rate of reduction is likely to increase with the increase of cycles.

Table 5.14 Sodium sulphate soundness mass loss values of the grey and pink andesite

Rock type	Uniaxial compressive strength (MPa)	
	Fresh specimen	After Na_2SO_4
Pink andesite	85.88 ± 28.80	67.55 ± 1.48
Grey andesite	98.95 ± 17.13	72.76 ± 10.91

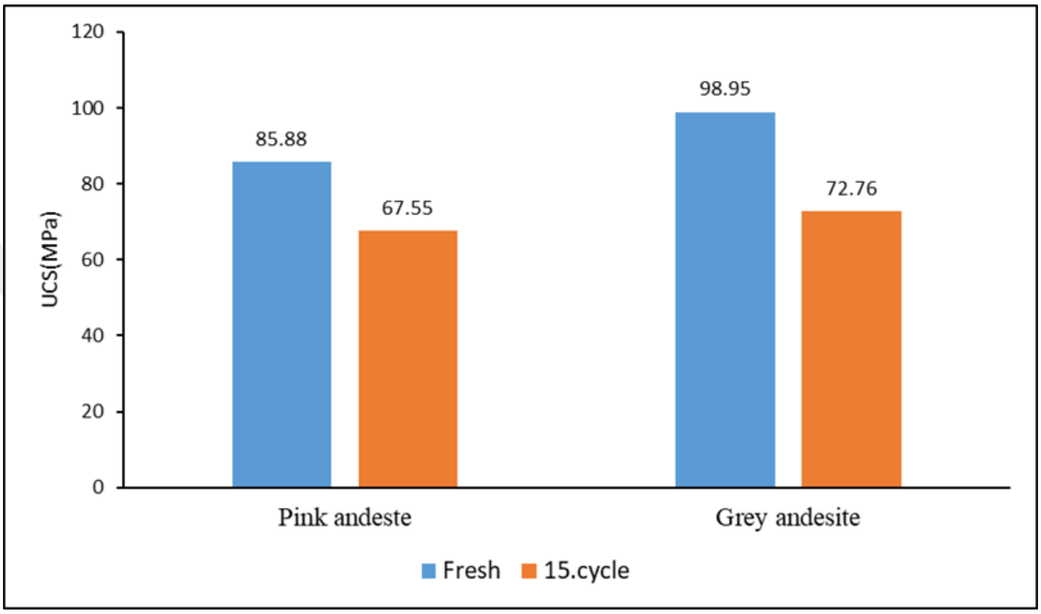

Figure 5.16 Uniaxial compressive strength after sodium sulphate

The changes in the physical properties of pink and grey andesite after sodium sulphate soundness test were evaluated at every 5th cycle of the test. The properties evaluated are dry and saturated unit weight, water absorption under atmospheric pressure, effective porosity, void ratio, dry and saturated sonic velocity. The results obtained are represented in form of a tables and graph demonstrating the changes of parameters at every 5th cycle until a total completion of the 15th cycle.

Saturated and dry unit weight pink and grey andesite reduce exponentially after the 5th cycle until it attains the 15th cycle of the Na_2SO_4 test. The saturated and dry unit weight values in pink andesite are 24.10 and 23.64 kN/m^3 while in grey andesite 24.17 and 24.05 kN/m^3 respectively (Table 5.15 and 5.16).

Water absorption under atmospheric pressure of pink and grey andesite increase as the number of cycles of Na_2SO_4 test increase. The values indicated in pink andesite is 2.73% and in grey andesite 1.41% (Table 5.15 and 5.16). The rate of increase is in pink andesite is 0.77% and 0.37% in grey andesite.

The increase of effective porosity of pink and grey andesite is exponential as it attains the 15th cycle of Na_2SO_4 test. The values obtained for effective porosity are 6.58% and 3.40% in pink and grey andesite respectively. In comparison to the initial porosity, the rate of increase is 1.81% and 0.88% in pink and grey andesite.

The void ratio after the test indicated a gradual increase till the completion of the test. The values recorded in pink andesite is 7.05, % and 3.53% in grey andesite. In relation to the initial void ratio the rate of increase is 1.14% and 0.93%, in pink and grey andesite respectively.

The dry and saturated sonic velocity of pink and grey andesite after Na_2SO_4 test indicated a gradual decrease in both rock types (Figure 5.17). The values recorded for saturated and dry sonic velocity are 4594 and 4546 m/s in pink andesite while 5005 and 4917 m/s in grey andesite respectively (Table 5.15 and 5.16). In relation to the initial sonic velocity in any physical state the rate of reduction is minor yet significant.

In conclusion all the physical properties indicated a change after the 15 cycles of Na_2SO_4 could presumably disintegrate the quality of a rock. The reduction of unit weight and sonic velocity in both rocks may be minor but significant if the test were to be continued. The increase of water absorption under atmospheric pressure, effective porosity and void ratio proved to be considerably important. The increase and reduction rates of all the parameters concluded that grey andesite is slightly resistant to Na_2SO_4 than pink andesite. This hypothesis is also proven by the physical disintegration of pink andesite on the core edges of some samples, that left one of the samples completely cracked along the fracture at the end of the test (Figure 5.17).

Table 5.15 Average measurements of physical properties of pink andesite after Na_2SO_4 soundness test

Physical properties	N	Number of cycles			
		0	5	10	15
Dry-γ (kN/m³)	5	23.97	23.95	23.77	23.64
Saturated-γ (kN/m³)	5	24.43	24.20	24.16	24.1
Watm (%)	5	1.96	2.35	2.74	2.73
Porosity (%n)	5	4.77	5.74	6.63	6.58
Void ratio (%e)	5	5.01	6.09	7.1	7.05
Dry P-wave (m/s)	5	4720	4580	4578	4546
Saturated P-wave (m/s)	5	4819	4686	4601	4594

Table 5.16 Average measurements of physical properties of grey andesite after Na_2SO_4 soundness test

Physical properties	N	Number of cycles			
		0	5	10	15
Dry -γ (kN/m³)	5	24.43	24.21	24.15	24.05
Sat - γ (kN/m³)	5	24.67	24.21	24.23	24.17
Watm (%)	5	1.01	1.13	1.39	1.41
Porosity (%n)	5	2.52	2.74	3.36	3.4
Void ratio (%e)	5	2.59	2.83	3.48	3.53
Dry P-wave (m/s)	5	5040	4952	4925	4917
Saturated P-wave (m/s)	5	5124	5098	5053	5005

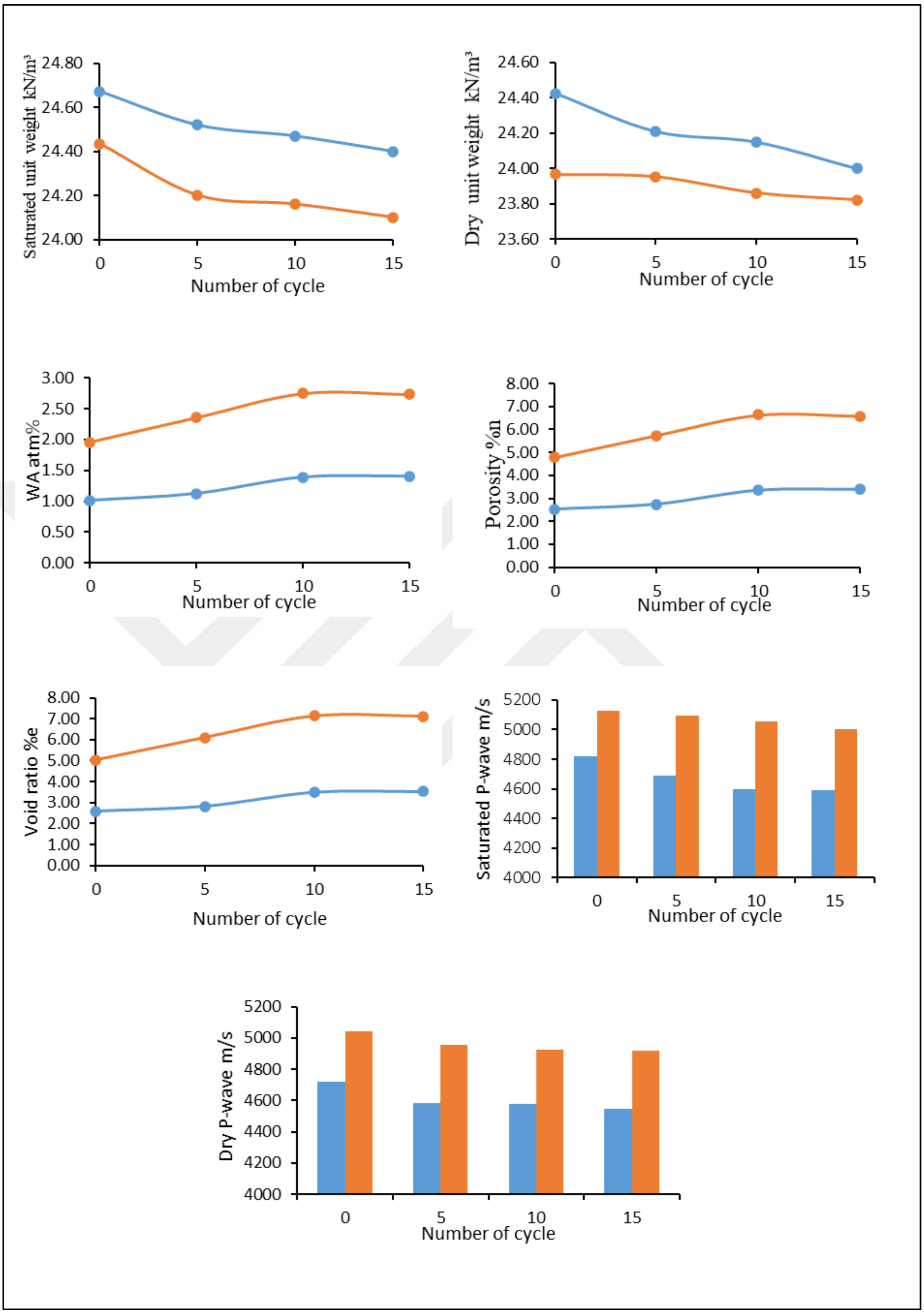

Figure 5.17 Variation of physical properties after sodium sulphate (Na_2SO_4) soundness test (blue bar shows the grey andesite and orange bar shows pink andesite

CHAPTER SIX
ROCK QUALITY EVALUATION

6.1 Saturation coefficient

The Saturation coefficient of a rock is the ratio of the rock water absorption at atmospheric pressure after 24hrs of complete immersion and its water absorption under atmospheric pressure (TS 699, 2009). A rock with a very high saturation coefficient value is prone to be deteriorated by freeze-thaw activity (RILEM, 1980). Hence, the saturation coefficient value is a useful input in assessing the durability of a rock under freeze-thaw conditions.

$$S = \frac{Water\ absorption\ at\ atmospheric\ pressure(\%)}{Water\ absorption\ at\ \ vacuum\ pressure(\%)} \qquad (6.1)$$

According to (Topal & Doyuran, 1997) if the saturation coefficient value greater the 0.80 it indicates low durability “susceptible to frost activity. However, a saturation coefficient between the interval of 0.66 and 0.77 gives an unreliable guide (Anon, 1975).

Table.6.1 Saturation coefficient values

Rock Type	WA (atm)%	WA (vac)%	Saturation coefficient
Pink andesite	2.48	4.30	0.58
Grey andesite	1.20	1.39	0.86

The saturation coefficient of grey andesite is 0.86. This value indicates that the grey andesite has a low durability (susceptible to frost activity). The saturation coefficient of the pink andesite is 0.58 indicating a high durability (susceptible to frost activity).
Conclusively the saturation coefficient values of the rock types indicate that the grey andesite is most likely to be affected from freeze-thaw activity compared to pink andesite. However, this coefficient and method alone is not considered as reliable to evaluate durability (Robinson, 1984; Topal & Doyuran, 1997; Yavuz & Topal, 2016).

6.2 Wet to Dry Strength Ratio

The presence of moisture in a rock tends to significantly influence the strength of a rock hence affecting its optimal performance. This mainly due to the clay contained in rock material whose morphology can either be swelling or non-swelling that absorbs water when subjected to wet conditions. Henceforth, to assess the influence of the moisture on rock strength Winkler (1986; 1993) suggested that the wet and dry ratio is based on the rupture modulus that is the resistance of uniaxial compressive strength test pressure. This method has proved to be a rapid method to ascertain the durability performance of rock.

This method further elaborates that the closer the saturated and dry uniaxial compressive strength are to each other, the higher the durability of the rock. Therefore, the lower the dry-saturated pressure resistance ratio and the lower the rock weathering resistance to water. (Winkler, 1993; Topal & Doyuran, 1997). The wet to dry strength ratio durability index evaluation is given as follows;

$$Strength\ ratio\% = \frac{Saturated\ UCS}{Dry\ UCS} \tag{6.2}$$

Table 6.2 Wet to dry strength ratio values

Rock type	Strength ratio %
Pink andesite	74.1
Grey andesite	78.5

The wet to dry strength ratio given by uniaxial compressive strength test for the grey and pink andesite rock is very close in percentage where grey is at 78.5% and pink at 74.1% percent respectively. According to Winkler (1986) durability classification this reveals that the two rock types are classed as “very good to good” durability.

Table 6.3 Wet to Dry strength ratio classification according to Winkler (1986)

Strength ratio	Description
>80	Excellent
80-70	Very good-good
60-70	Fair
50-60	poor
<50	Very poor

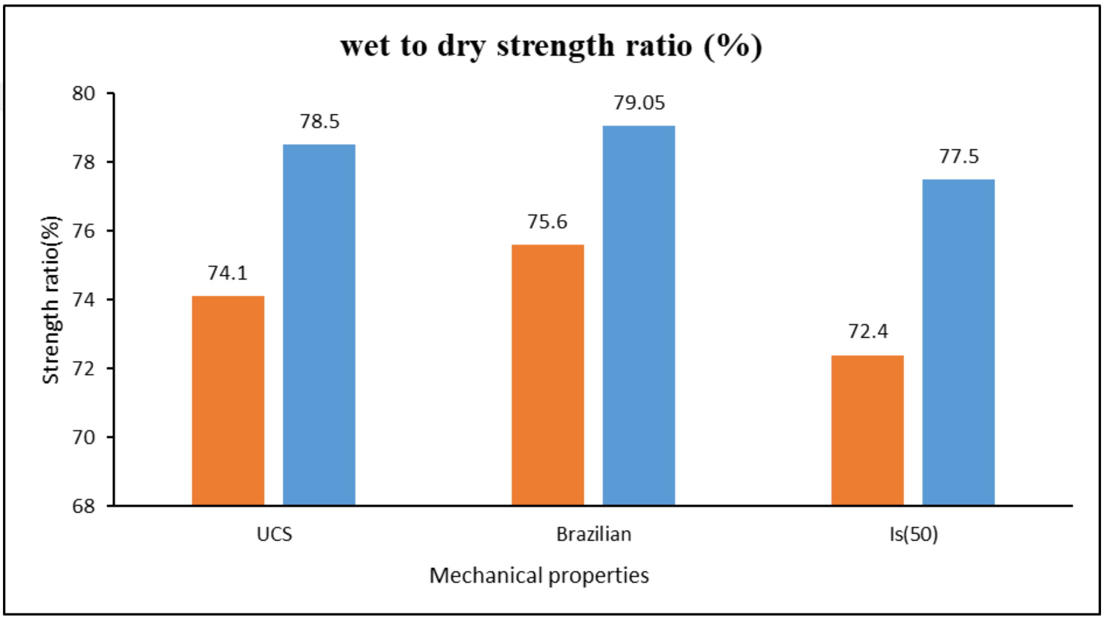

Figure 6.1 Wet to dry strength ratio percentages illustration graph for uniaxial compressive strength (UCS), Brazilian tensile strength and point load index

6.3 Static Rock Durability Index (RDIs)

The weathering and durability of rocks are the important factors in assessing their sustainability and performance as building material and engineering structure. However, these important factors cannot only be evaluated by one parameter. Thus, the combination of mechanical, chemical and physical tests of rocks are utilized in evaluating durability alongside rock strength. Rock durability index is most common used in evaluating the performance of rocks. Rock durability index indicators suggested by Fookes et al., (1988) incorporate all the rocks parameters and among the best methods is the dynamic rock durability index (RDId) and the static rock durability index (RDIs). Both of the methods are laboratory based.

In this study the rock durability indicator used is the static rock durability index (RDIs) to evaluate the weathering and durability of the specimen. The indices that are incorporated in this durability indicator are the mean of saturated and dry point load index, mass loss % after magnesium sulphate soundness test, water absorption % at atmospheric pressure and saturated surface and dry relative density.

Static rock durability indicator RDIs is expressed by (Fookes et al. (1988) as follows:

$$\text{RDIs} = \frac{\mathrm{I_S}\,(50)^{*} - 0.1(SST + 5WA)}{SG_{ssd}} \qquad (6.3)$$

Where;

Is (50): Dry and saturated corrected point-load strength index (ISRM, 1985)

SST: Mass loss after magnesium sulphate soundness test (Hosking & Tubey, 1969)

WA: Water absorption at atmospheric pressure (BSI, 1975; TS 699, 2009)

SGssd: Saturated surface and dry relative density (BSI, 1975; ISRM, 1981)

Table 6.4 Estimated classification of static rock durability (Fookes et al., 1988)

RDI s value Durability	Description
>2.5	Excellent
2.5 to (-1)	Good
(-1) to (-3)	Marginal
< (-3)	Poor

Table 6.5 Static Rock Durability Index (RDIs) values

Rock type	Is (50)	SST (%)	WA (%)	SGssd	RDIs	Fookes (1988) Classification
Pink andesite	5.64	0.49	2.48	2.44	1.78	Good
Grey andesite	6.34	0.41	1.20	2.50	2.28	Good

The static rock durability index (RDIs) values for Pink andesite is 1.78 and for grey andesite is 2.28 respectively (Table 6.6). According to Fookes et al. (1988) both rock types indicated “good durability” (Table 6.5).

CHAPTER SEVEN
DISCUSSION AND CONCLUSION

7.1 Discussion

This research study was directed to finding evidence of anisotropy, investigating its influence on rock strength and the quantification of the observed degree of anisotropy. In addition, the influence of weathering on rock quality. The study was applied on pink and grey andesite of Bornova mélange formation. The findings of the study are as follows:

According the study conducted under an optic light microscope the main mineral components revealed from thin section of pink and grey andesite are feldspar plagioclase, pyroxene, amphibole and biotite. The minerals indicated zonation of plagioclase, oxidized amphibole and displayed no alterations. However, there were a few unfilled fractures in pink andesite. In regards to anisotropy the minerals display very little to no evidence of anisotropy in pink and grey andesite rock, thus there was no distinct alignment of minerals in grey andesite while in pink andesite feldspar plagioclase minerals at $\beta = 45°$ and 75° demonstrated slight probable alignments.

The dry unit weight in the study in between 24.34 and 23.60 kN/m³. The indicated value in pink andesite is 23.60 kN/m³ while 24.34 kN/m³ was indicated in grey andesite. Based on Anon rock classification the dry unit weight of pink and grey andesite is classified as “medium”.

The effective porosity indicated in the study is between 5.91% and 2.89%. In pink andesite the porosity value indicated was 5.91% and in grey andesite 2.89%. According to Anon (1979) the porosity in pink andesite is classified as “medium” while that in grey andesite in classified as “low”. The remarkable difference of the porosity and its classification in between grey and pink andesite could be also be seen other closely related parameters thus the water absorption by weight under atmospheric pressure was higher in pink andesite than in grey andesite. Indicating an absorption of 2.48% in pink andesite and 1.18% in grey andesite respectively.

Furthermore, linear relation between porosity and unit weight (saturated and dry) established. The relation reveals that as the porosity values increase the unit weight values decrease.

P-wave velocity (Vp) values recorded for saturated and dry samples are between 5133.45-4966.39 m/s and 4689.13-4272.97 m/s respectively in grey andesite,4534.28-4768.67 m/s and 4272.97-3859.04 m/s respectively in pink andesite. The effect of anisotropy on p-wave velocity values is quite remarkable as the maximum velocity values are recorded at inclination angle β=90°, while the minimum velocity value of recorded at β=0° respectively for both rocks. It is observed that Vp-saturated values were higher than Vp-dry values. However, the difference in between the two physical states is quite minimal to conclude that the rocks are of high permeability and the degree of weathering is high, Based on Anon (1979) the P-wave velocity in pink andesite is classified as "high-moderate" ,while in grey andesite "very high-high" respectively.

The overall mean values of uniaxial compressive strength indicated for saturated and dry samples are between 72.26-98.99 MPa respectively in grey andesite, 53.94-85.88 MPa respectively in pink andesite. In function of their inclination angle the specimens indicated their highest compressive strength values at β = 90° in saturated and dry samples 85.2 MPa and 111.18 MPa respectively in pink andesite,79.96 and 110.74 MPa respectively in grey andesite. The lowest compressive strength values indicated in function of the anisotropy angles in saturated and dry samples were 36.4 MPa at β = 45°and 51.21 MPa at β= 30° respectively in pink andesite, 60.23 MPa and 84.33 MPa at β = 45° in grey andesite. Conclusively, the tendencies of uniaxial compressive strength values in function of the inclination angles are highest when angle is close to β = 90 °and β = 0° respectively, and lowest between β=30° and 45° respectively. According to ISRM (1981) the overall values of uniaxial compressive strength in respective to their physical state the specimens are classified as "high strength" in grey andesite, "medium-high strength" in pink andesite. The established relation between porosity and uniaxial compressive strength (UCS), display a strong correlation coefficient value in both rock types, thus it is observed that as porosity values increase the UCS values decrease.

The Brazilian tensile strength (BTS) overall mean values for saturated and dry samples are between 7.24 and 9.10 MPa respectively in grey andeste,3.81 and 5.03 respectively in pink andesite. The maximum Brazilian tensile strength values for saturated and dry samples were recorded at inclination β = 90° with values 9.71MPa and 7.95 in grey andesite,4.17 MPa and 5.80 MPa respectively in pink andesite. While the minimum values of BTS were recorded at β = 45° for saturated and dry samples are 6.05 MPa and 7.95 MPa in grey andesite, 3.40 MPa and 4.30 MPa respectively in Pink andesite. Conclusively, maximum values of Brazilian tensile strength were indicated at β = 0° and β = 90°, while the minimum values were indicated at 45° respectively.

The point load index strength ($Is_{(50)}$) overall mean values of saturated and dry specimens are 6.20MPa and 8.43MPa respectively in grey andesite,4.54 MPa and 6.74 MPa respectively in pink andesite. In function of anisotropy the maximum values of point load index for saturated and dry samples were indicated at β=0° with values 6.58 MPa and 9.82 MPa in grey andesite, 4.89 MPa and 7.18 MPa respectively in pink andesite. The minimum $Is_{(50)}$ values were indicated at β=90° for saturated and dry samples with values 5.83 MPa and 7.59 MPa respectively in grey andesite, 4.19 MPa and 6.32 MPa in pink andesite. According to Bieniawski (1975) the point load index exhibited in these samples is classified as “very high - high strength” in grey andesite, “high strength” in pink andesite.

The rock Bohme abrasion resistance volume loss values indicated were 7.33cm^3/50cm^2 in grey andesite, 8.28cm^3/50cm^2 in pink andesite respectively.

The degree of anisotropy exhibited by the specimens after critical analysis of P-wave (Vp), uniaxial compressive strength (UCS), Brazilian tensile strength and point load index ($Is_{(50)}$) are as follows:

- The velocity anisotropy index (VA) values indicated for saturated and dry samples are 1.09 and 1.03 respectively in grey andesite,1.03 and 1.05 respectively in pink andesite. Based on Tsidzi (1997) the degree of anisotropy exhibited in pink and grey andesite is classified as “isotropic”.

- The degree of compressive strength anisotropy index (Rc) values indicated for saturated and dry samples is 2.34 and 2.17 respectively in pink andesite,1.33 and 1.31 respectively in grey andesite. Based on (Ramamurthy, 1993) compressive strength anisotropy index classification, the degree of anisotropy exhibited in grey andesite was classified as “fairly anisotropic” while in pink andesite “moderately anisotropic”.

- The Brazilian tensile strength anisotropy index values indicated for saturated and dry samples are 1.23 and 1.35 respectively in pink andesite,1.28 and 1.22 respectively in grey andesite. Based on Ramamurthy (1993) and Singh et al (1989) anisotropy index classification, the degree of anisotropy exhibited in pink and grey andesite was classified “fairly anisotropic”.

- Point load anisotropy index ($Ia_{(50)}$) values exhibited in saturated and dry samples are 1.17 and 1.13 in pink andesite, 1.13 and 1.22 respectively in grey andesite. Based on ISRM (1985) point load anisotropy index classification it reveals that pink and grey andesite are classified as “fairly anisotropic”.

Conclusively, overall, the degree of anisotropy exhibited is classified as “fairly anisotropic in grey andesite while in pink andesite “moderately-fairly anisotropic” in pink andesite. The moderately anisotropic classification in pink andesite could be attributed to the alignment of minerals as observed in the mineralogical study or other rock features.

The mass loss of wetting-drying accelerated test values recorded are 0.31% in pink andesite and 0.23% in grey andesite. Pink andesite demonstrated the highest mass loss value after the 80th cycle of wetting and drying test. The samples displayed no physical deterioration after the test.

The mass loss values indicated by the 45th freezing and thawing cycle are 0.49% in pink andesite,0.34% in grey andesites. The highest mass loss after the 45th cycle was recorded in pink andesite. After the 45th cycle, the samples displayed no remarkable physical disintegration.

After 5 cycles of magnesium sulphate ($MgSO_4$) the mass loss values indicated are 0.49% in pink andesite ,0.41% in grey andesite respectively. The lowest mass loss value was indicated in grey andesite. The samples appeared pale in colour after test. However, there was no significant physical disintegration.

The 15th cycle of Sodium sulphate (Na_2SO_4) crystallization soundness test mass loss values recorded are 1.12% in pink andesite,0.54% in grey andesite respectively. At the completion of sodium sulphate’s 15th cycle, pink andesite samples displayed a disintegration around the edges of the cores and left one of samples the cracked, while there was no remarkable physical disintegration in grey andesite.

After all the accelerated weathering tests, Sodium sulphate soundness salt crystallization test is observed to have had the most effect on the specimen’s mass loss and disintegration. All the specimens maintained their original morphology after wetting-drying, freezing-thawing and magnesium sulphate soundness test except after sodium sulphate test where pink andesite samples disintegrated around the core edges and one of them cracked along a fracture.

The changes observed in physical and mechanical parameters after the accelerated weathering tests are a gradual reduction in saturated and dry unit weight, p-wave velocity and uniaxial compressive strength values, while an increase in water absorption under atmospheric pressure, porosity and void ratio values were remarked.

The rocks saturation coefficient values of the specimens are 0.58 in pink andesite,0.86 in grey andesite respectively. Considering the data obtained, the saturation coefficient of pink andesite is lower than 0.80, in this case the durability of this rock is against freezing and thawing activity is high. The saturation coefficient of grey andesite is higher than 0.80, henceforth, the durability of this rock against freezing and thawing activity is low.

The saturation and dry uniaxial compressive strength ratio (UCSsat/UCSdry) values of pink and grey andesite are 74.1% and 78.5% respectively. Considering the data obtained, based on Winkler (1986) durability classification, pink and grey andesite was classified as “good-very good” durability.

The static rock durability index (RDIs) values obtained for pink and grey andesite are 1.78 and 2.28 respectively. According to Fookes et al the durability indicated in these rocks is classified as “good durability”.

7.2 Conclusion

Based on the field and laboratory analysis, the following conclusions were drawn from the study:

a. The main mineralogical components of the pink and grey andesite of the Bornova mélange formation are plagioclase, biotite, pyroxene and amphibole. In addition, the minerals present little to no alignment except in a few pink andesite blocks where the alignment of plagioclase was significant.

b. The X-ray diffraction analysis revealed contents of clay, mica and smectite that may directly affect the of the permeability of a rock.

c. The effective porosity of pink and grey andesite has a strong inversely relationship with other parameters. Thus, as porosity increases, the unit weight and UCS decreases.

d. The uniaxial compressive strength of pink andesite is classified as “medium-high strength” while grey andesite is classified as “high strength” based on Bienwiaski (1989) UCS classification. These classifications are held up by the UCSsat/UCSdry ratio which are relatively high.

e. The Uniaxial compressive strength changes in pink and grey andesite in relation to the inclination angle rocks demonstrated a remarkable decrease in strength between angle β=30° and β = 45° and indicated their maximum strength at β = 0° and β = 90° respectively. Based on the anisotropy index ratios obtained, the degree of anisotropy pronounced in pink and grey andesite is classified as “fairly anisotropic” that is based on Singh et al (1989) and Ramamurthy (1993) anisotropy classification. In conclusion the anisotropy exhibited in pink and grey andesite has no significant effect on the rock’s strength.

f. The effect of accelerated weathering tests on physical and mechanical properties of pink and grey andesite, is remarkable yet not significant. According to static rock durability index data obtained the rocks are classified as “very good-good” durability after Winkler’s (1986) rock durability classification.

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APPENDICES

Appendix A Physical Properties

Table A.1 Pink andesite values of physical properties

Sample no.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm	%n	γsat (kN/m³)	γdry (kN/m³)	e%
Block 8-1	326.89	559.67	546.99	2.32	5.45	23.59	23.05	5.76
2	335.88	568.08	557.85	1.83	4.41	24.00	23.57	4.61
3	330.94	564.57	555.07	1.71	4.07	23.71	23.31	4.24
4	325.14	558.35	544.77	2.49	5.82	23.49	22.92	6.18
5	325.58	559.01	545.92	2.40	5.61	23.49	22.94	5.94
6	333.66	567.55	558.89	1.55	3.70	23.80	23.44	3.84
7	330.01	563.73	554.54	1.66	3.93	23.66	23.28	4.09
Block 15-1	321.83	562.33	539.86	4.16	9.34	22.94	22.02	10.31
2	321.34	558.89	538.9	3.71	8.42	23.08	22.25	9.19
3	340.73	580.29	565.55	2.61	6.15	23.76	23.16	6.56
4	336.31	576.3	559.59	2.99	6.96	23.56	22.87	7.48
5	338.98	578.44	563.28	2.69	6.33	23.70	23.08	6.76
6	318.17	556.5	534.5	4.12	9.23	22.91	22.00	10.17
7	336.63	578.52	561.12	3.10	7.19	23.46	22.76	7.75
8	343.89	583.66	569.32	2.52	5.98	23.88	23.29	6.36
9	334.22	574.28	555.51	3.38	7.82	23.47	22.70	8.48
10	326.5	567.09	546.32	3.80	8.63	23.12	22.28	9.45
11	337.8	576.19	559.88	2.91	6.84	23.71	23.04	7.34
12	340.23	578.12	563.7	2.56	6.06	23.84	23.25	6.45
13	333.96	572.25	556.65	2.80	6.55	23.56	22.92	7.01
14	315.31	551.65	530.73	3.94	8.85	22.90	22.03	9.71
Block 16 -1	383.37	625.16	615.45	1.58	4.02	25.36	24.97	4.18
2	378.87	618.81	607.78	1.81	4.60	25.30	24.85	4.82
3	376.46	613.63	603.62	1.66	4.22	25.38	24.97	4.41
4	373.46	610.05	599.61	1.74	4.41	25.30	24.86	4.62
5	358.41	593.98	577.76	2.81	6.89	24.74	24.06	7.39
6	369.66	613.11	596.72	2.75	6.73	24.71	24.05	7.22
7	374.87	611.03	600.26	1.79	4.56	25.38	24.93	4.78
8	371.77	614.57	598.71	2.65	6.53	24.83	24.19	6.99
9	362.1	596.93	582.35	2.50	6.21	24.94	24.33	6.62
10	379.24	620.8	608.19	2.07	5.22	25.21	24.70	5.51
11	374.86	619.03	604.04	2.48	6.14	24.87	24.27	6.54

Table A.1 Continues

Sample no.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm	%n	γsat (kN/m³)	γdry (kN/m³)	e%
Block 18 -1	354.18	592.79	576.12	2.89	6.99	24.37	23.69	7.51
2	350.87	585.52	568.3	3.03	7.34	24.48	23.76	7.92
3	360.61	599.64	584.13	2.66	6.49	24.61	23.97	6.94
4	352.44	592.8	575.78	2.96	7.08	24.19	23.50	7.62
5	357.93	598.3	582.34	2.74	6.64	24.42	23.77	7.11
Block 20 -1	362.02	603.2	594.86	1.40	3.46	24.54	24.20	3.58
2	343.04	581.7	567.84	2.44	5.81	23.91	23.34	6.17
3	357.84	596.19	588.37	1.33	3.28	24.54	24.22	3.39
4	341.34	577.27	561.57	2.80	6.65	24.00	23.35	7.13
Block 21-1	354.4	594.3	579.72	2.52	6.08	24.30	23.71	6.47
2	360.03	602.57	587.38	2.59	6.26	24.37	23.76	6.68
3	356.37	597.37	582.28	2.59	6.26	24.32	23.70	6.68
4	357.84	599.11	584.77	2.45	5.94	24.36	23.78	6.32
Block 25-1	378.11	621.11	613.89	1.18	2.97	25.07	24.78	3.06
2	375.06	620.9	614.05	1.12	2.79	24.78	24.50	2.87
3	370.67	615.89	609.5	1.05	2.61	24.64	24.38	2.68
			Mean	2.48	5.91	24.18	23.60	6.31
			Standard deviation	0.76	1.65	0.70	0.81	1.87

Table A.2 Grey andesite values of physical properties

Rock Sample	Wsub(gr)	Wsat(gr)	W_{dry} (gr)	Watm	%n	γsat (kN/m³)	γdry (kN/m³)	e%
Block 7-1	382.59	617.14	611.22	0.97	2.52	25.81	25.56	2.59
2	386.8	625.06	618.98	0.98	2.55	25.74	25.49	2.62
3	391.71	632.88	626.58	1.01	2.61	25.74	25.49	2.68
4	383.37	619.47	613.26	1.01	2.63	25.74	25.48	2.7
5	389.4	628.71	621.91	1.09	2.84	25.77	25.49	2.92
6	390.07	629.65	622.93	1.08	2.8	25.78	25.51	2.89
Block 9-2	388.56	631.06	625.36	0.91	2.35	25.53	25.3	2.41
3	389.83	633.79	627.08	1.07	2.75	25.49	25.22	2.83
4	390.11	634.08	627.02	1.13	2.89	25.5	25.21	2.98
5	386.31	628.33	622.86	0.88	2.26	25.47	25.25	2.31
Block 10 -1	384.62	630.28	626.74	0.56	1.44	25.17	25.03	1.46
2	376.9	612.22	608.89	0.55	1.42	25.52	25.38	1.44
3	385.95	627.72	624.14	0.57	1.48	25.47	25.32	1.5
4	375.31	609.38	606	0.56	1.44	25.54	25.4	1.47
5	385.99	628.03	624.74	0.53	1.36	25.45	25.32	1.38
6	369.55	600.28	597.01	0.55	1.42	25.52	25.38	1.44
7	385.71	626.12	622.61	0.56	1.46	25.55	25.41	1.48
8	371.96	604.58	600.8	0.63	1.62	25.5	25.34	1.65

Table A.2 continues

Sample no.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm	%n	γsat (kN/m³)	γdry (kN/m³)	e%
Block 11-1	384.26	626.04	620.93	0.82	2.11	25.4	25.19	2.16
2	380.54	620.59	615.53	0.82	2.11	25.36	25.15	2.15
3	368.54	601.89	595.63	1.05	2.68	25.3	25.04	2.76
4	380.82	621.24	615.94	0.86	2.2	25.35	25.13	2.25
5	383.87	625.97	619.97	0.97	2.48	25.36	25.12	2.54
6	381.51	621.43	616.61	0.78	2.01	25.41	25.21	2.05
7	383.81	625.08	619.89	0.84	2.15	25.42	25.2	2.2
8	382.81	624.56	618.77	0.94	2.4	25.34	25.11	2.45
9	384.85	626.74	622.1	0.75	1.92	25.42	25.23	1.96
10	380.76	622.17	615.58	1.07	2.73	25.28	25.01	2.81
Block 12-1	363.36	596.3	590.94	0.91	2.3	25.11	24.89	2.36
2	376.37	616.53	610.92	0.92	2.34	25.18	24.95	2.39
3	380.27	622.57	617.65	0.8	2.03	25.21	25.01	2.07
4	376.37	616.12	611.3	0.79	2.01	25.21	25.01	2.05
Block 13-1	334.63	570.56	561.11	1.68	4.01	23.72	23.33	4.17
2	345.48	588.62	578.49	1.75	4.17	23.75	23.34	4.35
3	331.76	564.66	555.02	1.74	4.14	23.78	23.38	4.32
4	339.17	573.88	566.55	1.29	3.12	23.99	23.68	3.22
5	343.08	583.56	573.87	1.69	4.03	23.81	23.41	4.2
6	346.46	587.36	579.22	1.41	3.38	23.92	23.59	3.5
7	337.48	577.91	566.63	1.99	4.69	23.58	23.12	4.92
8	330.09	564.93	553.63	2.04	4.81	23.6	23.13	5.06
9	341.5	584.12	573.45	1.86	4.4	23.62	23.19	4.6
10	342.8	584.16	573.34	1.89	4.48	23.74	23.3	4.69
11	342.3	584.37	573.88	1.83	4.33	23.68	23.26	4.53
12	344.68	584.4	576.62	1.35	3.25	23.92	23.6	3.35
13	331.4	564.88	556.25	1.55	3.7	23.73	23.37	3.84
14	341.89	577.5	570.09	1.3	3.15	24.05	23.74	3.25
15	340.76	582.19	571.22	1.92	4.54	23.66	23.21	4.76
16	345.53	587.47	577.85	1.66	3.98	23.82	23.43	4.14
17	347.12	588.82	578.89	1.72	4.11	23.9	23.5	4.28
18	346.66	590.59	580.64	1.71	4.08	23.75	23.35	4.25
19	335.88	569.71	560.99	1.55	3.73	23.9	23.54	3.87
20	333.34	568.86	558.08	1.93	4.58	23.69	23.25	4.8
21	347.19	589.63	581.58	1.38	3.32	23.86	23.53	3.43
22	344.12	585.73	575.63	1.75	4.18	23.78	23.37	4.36

Table A.2 continues

Sample no.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm	%n	γsat (kN/m³)	γdry (kN/m³)	e%
Block 14-1	340.38	581.06	571.51	1.67	3.97	23.68	23.29	4.13
2	349.74	590.72	582.1	1.48	3.58	24.05	23.7	3.71
3	342.21	583.12	572.74	1.81	4.31	23.74	23.32	4.5
4	348.8	591.88	583.23	1.48	3.56	23.89	23.54	3.69
5	351.42	595.27	585.49	1.67	4.01	23.95	23.55	4.18
6	346.63	586.69	578.86	1.35	3.26	23.97	23.65	3.37
7	336.78	572.08	562.2	1.76	4.2	23.85	23.44	4.38
9	334.52	570.23	559.38	1.94	4.6	23.73	23.28	4.83
10	352.43	593.69	585.8	1.35	3.27	24.14	23.82	3.38
11	339.99	581.53	571	1.84	4.36	23.62	23.19	4.56
12	346.13	586.08	578.02	1.39	3.36	23.96	23.63	3.48
13	350.89	591.86	584.12	1.33	3.21	24.09	23.78	3.32
14	351.04	593.95	584.3	1.65	3.97	23.99	23.6	4.14
Block 17-1	384.37	626.32	622.76	0.57	1.47	25.39	25.25	1.49
2	384.75	625.36	621.75	0.58	1.5	25.5	25.35	1.52
3	384.85	624.73	621.39	0.54	1.39	25.55	25.41	1.41
4	383.47	624.48	620.41	0.66	1.69	25.42	25.25	1.72
5	378.29	618.18	613.4	0.78	1.99	25.28	25.08	2.03
6	378.11	617.95	614.19	0.61	1.57	25.28	25.12	1.59
7	387.89	629.98	626.7	0.52	1.35	25.53	25.4	1.37
Block 19-1	346.46	586.94	577.87	1.57	3.77	23.94	23.57	3.92
2	349.56	587.62	579.2	1.45	3.54	24.21	23.87	3.67
3	346.7	585.75	577.09	1.5	3.62	24.04	23.68	3.76
4	338.75	573.89	564.11	1.73	4.16	23.94	23.53	4.34
5	350.91	591.79	583.35	1.45	3.5	24.1	23.76	3.63
6	345.1	582.82	573.56	1.61	3.9	24.05	23.67	4.05
Block 22-1	369.14	614.2	609.98	0.69	1.72	24.84	24.42	1.75
2	363.04	607.01	602.68	0.72	1.77	24.66	24.23	1.81
3	369.41	612.54	607.98	0.75	1.88	24.97	24.53	1.91
4	366.14	608.49	603.69	0.8	1.98	24.88	24.44	2.02
5	365.49	606.39	601.76	0.77	1.92	24.95	24.51	1.96
Block 23-1	365.04	607.32	600.15	1.19	2.96	24.59	24.3	3.05
2	365.86	608.57	602.87	0.95	2.35	24.6	24.37	2.4
3	365.15	606.57	600.89	0.95	2.35	24.65	24.42	2.41
4	366.45	606.78	601.1	0.94	2.36	24.77	24.54	2.42

Table A.2 continues

Sample no.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm	%n	γsat (kN/m³)	γdry (kN/m³)	e%
Block 24-1	362.65	604.54	598.5	1.01	2.5	24.52	24.27	2.56
2	369.45	612.65	605.56	1.17	2.92	24.71	24.43	3
3	365.04	607.5	600.5	1.17	2.89	24.58	24.3	2.97
4	369.98	615.09	608.5	1.08	2.69	24.62	24.35	2.76
5	364.78	613.56	607.67	0.97	2.37	24.19	23.96	2.42
6	360.98	605.64	599.5	1.02	2.51	24.28	24.04	2.57
7	361.89	606.54	600.78	0.96	2.35	24.32	24.09	2.41
8	369.8	617.54	610.5	1.15	2.84	24.45	24.17	2.92
9	365.48	606.46	601.23	0.87	2.17	24.69	24.48	2.22
10	363.56	603.53	597.47	1.01	2.53	24.67	24.42	2.59
			Mean	1.18	2.89	24.63	24.34	2.97
			STD	0.44	0.99	0.74	0.82	1

Appendix B Water absorption under vacuum pressure

Table B.1 Grey andesite values of water absorption under vacuum pressure

Sample No.	Wsub(gr)	Ws(gr)	Wd(gr)	Wvac%
Block10-1	389.91	635.62	626.74	1.42
2	378.55	618.94	608.89	1.65
3	388.23	633.7	624.14	1.53
Block 11-1	384.66	630.35	620.93	1.52
2	381.8	623.8	615.53	1.34
3	369.61	602.8	595.63	1.20
Block 17-1	384.26	630.21	622.76	1.20
2	384.59	629.27	620.75	1.37
3	385.34	629.18	621.39	1.25
Mean				1.39
Standard deviation				0.16

Table B.2 Pink andesite values of water absorption under vacuum pressure

Sample No.	Wsub(gr)	Ws(gr)	Wd(gr)	Wvac%
Block 8-1	336.55	568.97	546.99	4.02
2	343.8	575.91	557.85	3.24
3	340.7	574.25	555.07	3.46
Block 15-1	334.25	574.27	539.86	6.37
2	333.54	571.31	538.9	6.01
3	350.13	589.46	565.55	4.23
Block 18-1	359.09	597.62	576.12	3.73
2	356.95	591.63	568.3	4.11
3	365.51	604.61	584.13	3.51
Mean				4.30
Standard deviation				1.13

Appendix C P-wave velocity

Table C.1 Pink andesite P-wave velocity values

Sample No.	Angle (°)	Length(mm)	Pundit-Sat (µs)	Pundit-Dry (m/s)	Pundit-Dry (µs)	Vp-Dry (m/s)
6_5	0	109.14	25.30	28.10	4313.64	3883.81
6_7	0	108.59	25.30	28.10	4292.00	3864.32
6_8	0	109.15	25.30	28.60	4314.13	3816.35
5_3	0	109.17	25.50	26.70	4280.98	4088.58
5_4	0	109.21	25.50	27.50	4282.65	3971.18
4_6	0	109.71	23.40	25.40	4688.46	4319.29
4_3	0	110.38	21.40	23.90	5158.06	4618.51
6_1	0	107.97	25.40	28.10	4250.69	3842.26
16_{11}	0	106.36	29.40	33.80	3617.52	3146.60
16_{10}	0	108.34	27.60	31.40	3925.27	3450.24
18_5	0	108.62	28.00	31.50	3879.29	3448.25
8_5	30	110.22	22.90	25.30	4812.99	4356.42
16_3	30	109.07	24.20	27.80	4507.13	3923.47
8_6	30	110.30	22.90	24.50	4816.70	4502.14
8_3	30	110.50	22.80	25.00	4846.49	4420.00
5_2	30	109.03	25.50	27.30	4275.49	3993.59
15_2	30	109.47	28.20	30.80	3882.00	3554.30
15_{14}	30	108.69	29.10	32.30	3735.05	3365.02
15_3	45	108.29	25.60	28.90	4229.98	3746.97
15_4	45	109.70	26.80	29.70	4093.28	3693.60
15_6	45	109.45	25.10	28.60	4360.36	3826.75
15_8	45	109.59	25.50	28.20	4297.75	3886.26
15_9	45	109.52	25.20	30.60	4345.83	3578.92
15_{10}	45	108.96	25.20	28.30	4323.61	3850.00
15_{12}	45	108.35	25.20	29.10	4299.60	3723.37
15_{13}	45	108.01	23.30	28.80	4635.62	3750.35
16_6	45	107.52	25.90	27.40	4151.16	3923.91
8_7	45	110.45	23.30	25.20	4740.34	4382.94
8_2	45	110.30	22.80	23.80	4837.72	4634.45
15_1	45	108.00	25.70	28.50	4202.24	3789.39
15_5	45	110.73	25.80	28.70	4291.86	3858.19
15_7	45	108.56	24.20	27.90	4485.95	3891.04
15_{11}	45	108.89	25.30	27.60	4303.95	3945.29
16_2	45	108.31	22.10	27.00	4900.90	4011.48
25_1	45	108.90	21.40	22.10	5088.79	4927.60
3_6	60	108.71	23.90	27.30	4548.43	3981.96
3_7	60	108.35	23.90	27.60	4533.58	3925.82
25_3	60	109.87	20.40	21.60	5385.78	5086.57

Table C.1   continues

Sample No.	Angle (°)	Length(mm)	Pundit-Sat (µs)	Pundit-Dry (m/s)	Pundit-Dry (µs)	Vp-Dry (m/s)
18_1	60	110.09	24.10	29.30	4568.05	3757.34
18_2	60	109.99	24.40	29.20	4507.58	3766.61
6_2	60	109.50	24.20	28.30	4524.79	3869.26
16_5	60	108.32	25.90	26.30	4182.24	4118.63
18_4	60	108.30	23.80	25.20	4550.42	4297.62
18_3	60	108.01	23.20	27.10	4655.60	3985.61
6_3	60	107.52	24.20	28.10	4442.77	3826.16
16_9	60	110.22	23.20	28.60	4750.75	3853.76
4_7	90	109.17	23.40	26.40	4665.28	4135.13
4_8	90	108.99	23.40	26.50	4657.48	4112.64
4_{10}	90	107.85	23.40	26.80	4608.76	4024.07
4_{11}	90	108.37	22.40	27.30	4837.72	3969.41
8_1	90	109.07	22.90	25.10	4762.99	4345.52
8_4	90	110.46	22.30	24.70	4953.14	4471.86
16_4	90	110.09	24.20	26.80	4549.28	4107.93
3_3	90	110.30	24.20	25.90	4557.95	4258.78
3_4	90	110.50	24.30	26.10	4547.33	4233.72
4_1	90	109.87	23.40	27.10	4695.30	4054.24
4_2	90	110.09	23.20	27.80	4745.26	3960.07
Mean					4485.93	4002.24
STD					337.36	352.93

Table C.2 Grey andesite P-wave velocity values

Sample No.	Angle (°)	Length(mm)	Pundit-Sat (µs)	Pundit-Dry (µs)	Vp-Sat (m/s)	Vp-Dry (m/s)
7_1	0	109.09	21.80	25.10	5004.24	4346.31
7_4	0	108.00	22.50	24.70	4800.00	4372.47
7_5	0	108.00	21.90	25.30	4931.51	4268.77
11_6	0	108.00	21.00	21.90	5142.86	4931.51
12_3	0	108.00	21.20	22.60	5094.34	4778.76
13_2	0	108.00	22.40	23.90	4821.43	4518.83
13_{21}	0	109.28	22.40	24.30	4878.35	4496.91
7_2	0	108.99	21.80	24.10	4999.31	4522.20
7_3	0	107.85	21.90	24.30	4924.43	4438.07
11_2	0	108.37	21.60	21.90	5016.90	4948.17
11_8	0	108.71	21.40	22.20	5079.79	4896.73
14_1	0	108.35	22.90	26.10	4731.55	4151.44
14_6	0	108.29	22.30	25.90	4855.94	4180.98
192	0	109.70	20.90	23.70	5248.80	4628.69
1_1	30	109.45	22.90	23.90	4779.26	4579.29

Table C.2 continues

Sample No.	**Angle (°)**	**Length(mm)**	**Pundit-Sat (µs)**	**Pundit-Dry (µs)**	**Vp-Sat (m/s)**	**Vp-Dry (m/s)**
1_2	30	109.59	22.40	23.90	4892.52	4585.46
1_3	30	109.52	22.40	23.90	4889.06	4582.22
1_8	30	108.96	22.10	24.90	4930.09	4375.70
1_4	30	108.35	21.90	22.90	4947.49	4731.44
1_5	30	108.01	21.40	22.90	5047.20	4716.59
2_3	30	107.52	21.90	22.90	4909.36	4694.98
2_4	30	109.20	21.70	22.40	5032.26	4875.00
1_6	45	107.67	23.10	24.20	4660.82	4448.97
2_2	45	108.53	23.10	24.30	4698.16	4466.15
2_6	45	108.24	22.10	24.40	4897.74	4436.07
9_5	45	109.91	21.40	23.20	5135.86	4737.39
14_2	45	108.79	21.80	24.70	4990.48	4404.55
17_3	45	109.60	18.90	20.70	5798.94	5294.69
10_8	45	109.07	20.30	21.90	5372.91	4980.37
19_3	45	108.87	21.30	23.20	5111.03	4692.46
19_4	45	109.60	21.40	23.30	5121.26	4703.65
13_{15}	45	109.21	22.90	24.10	4769.10	4531.64
$13_{.18}$	45	108.71	22.50	24.00	4831.44	4529.48
24_6	45	109.84	21.40	22.80	5132.83	4817.65
24_7	45	109.20	21.40	22.80	5102.80	4789.47
13_3	45	107.67	22.30	23.90	4828.03	4504.81
24_{10}	45	108.46	21.90	22.40	4952.51	4841.96
2_1	45	108.55	19.90	22.30	5454.90	4867.83
7_6	45	108.65	22.90	24.50	4744.65	4434.80
9_4	45	109.13	21.80	23.40	5005.96	4663.68
11_9	45	108.70	21.90	23.10	4963.58	4705.74
11_{10}	45	108.72	21.40	22.20	5080.26	4897.18
12_1	45	108.73	21.30	22.90	5104.69	4748.03
12_4	45	109.21	20.80	22.20	5250.60	4919.48
13_5	45	108.24	22.30	25.10	4853.81	4312.35
14_{10}	45	108.94	21.80	25.30	4997.13	4305.83
14_{11}	45	108.60	23.70	26.80	4582.17	4052.15
17_7	45	108.70	19.40	21.60	5602.84	5032.18
17_2	45	109.20	19.20	21.20	5687.50	5150.94
19_1	45	108.99	21.70	23.70	5022.70	4598.84
19_6	45	108.92	21.30	22.80	5113.50	4777.08
24_4	45	109.57	21.40	22.50	5119.86	4869.56
24_2	45	108.50	21.20	22.80	5118.04	4758.88
23_4	45	110.28	21.40	22.00	5153.15	5012.61
23_2	45	110.27	21.00	22.50	5251.07	4901.00
24_3	45	109.04	21.30	22.30	5119.13	4889.57

Table C.2 continues

11_5	60	108.53	21.80	22.30	4978.33	4866.70
14_{14}	60	108.24	21.90	23.70	4942.47	4567.09
14_9	60	109.91	22.40	27.60	4906.58	3982.16
$13_{.9}$	60	108.79	22.40	24.10	4856.81	4514.21
$24_{.8}$	60	109.60	19.90	20.90	5507.54	5244.02
17_1	60	109.07	21.30	22.40	5120.66	4869.20
10_5	60	109.93	20.40	22.30	5388.48	4929.37
11_7	60	109.29	21.40	22.20	5106.89	4922.86
17_6	60	109.00	20.40	22.30	5343.14	4887.89
9_1	90	108.00	21.60	22.80	5000.00	4736.84
10_4	90	109.00	20.40	21.90	5343.14	4977.17
11_4	90	108.00	21.80	22.70	4954.13	4757.71
12_2	90	108.00	20.90	22.60	5167.46	4778.76
13_1	90	108.00	23.20	25.30	4655.17	4268.77
13_6	90	108.00	22.30	23.50	4843.05	4595.74
13_{10}	90	109.00	23.10	24.80	4718.61	4395.16
13_{16}	90	108.00	22.80	25.00	4736.84	4320.00
10_7	90	108.87	20.30	21.80	5362.81	4993.81
17_4	90	109.60	19.40	22.00	5649.23	4981.59
19_5	90	109.21	21.40	23.20	5103.39	4707.44
17_5	90	108.71	19.40	21.30	5603.48	5103.64
23_3	90	109.84	21.40	22.90	5132.83	4796.62
24_5	90	110.53	20.40	21.80	5417.89	5069.95
24_1	90	110.53	20.80	21.90	5313.70	5046.80
Mean					5059.23	4687.64
STD					251.30	273.07

Appendix D Uniaxial Compressive Strength

Table D.1 Grey andesite saturated uniaxial compressive strength values

Sample No.	Angle (°)	Length(mm)	Diameter(mm)	L/D	K/N	area(cm²)	Kg/cm^2	σc(MPa)
7_{1}	0	109.09	52.62	2.07	171.50	22.37	891.63	87.38
7_{4}	0	108.00	52.64	2.05	125.00	22.20	649.87	63.69
7_{5}	0	108.00	52.63	2.05	125.00	22.20	649.87	63.69
11_{6}	0	108.00	52.65	2.05	132.80	22.21	690.42	67.66
12_{3}	0	108.00	52.54	2.06	121.80	22.15	633.24	62.06
13_{2}	0	108.00	52.59	2.05	119.60	22.18	621.80	60.94
13_{21}	0	109.28	53.35	2.05	113.90	22.77	592.16	58.03
1_{9}	30	109.00	53.37	2.04	213.20	22.74	1108.42	108.63
1_{12}	30	108.00	53.36	2.02	124.70	22.57	648.31	63.53
1_{15}	30	108.00	53.34	2.02	213.50	22.56	1109.98	108.78
1_{16}	30	109.00	53.4	2.04	119.70	22.75	622.32	60.99
2_{7}	30	110.07	52.56	2.09	127.60	22.50	663.39	65.01
1_{13}	30	109.01	53.35	2.04	213.10	22.73	1107.90	108.57
1_{14}	30	109.64	52.32	2.10	270.10	22.31	1404.24	137.62
2_{5}	30	108.90	53.3	2.04	177.90	22.69	924.90	90.64
24_{10}	45	108.46	51.87	2.09	122.50	21.89	636.88	62.41
2_{1}	45	108.55	53.43	2.03	127.80	22.69	664.43	65.11
7_{6}	45	108.65	52.4	2.07	136.70	22.19	710.70	69.65
9_{4}	45	109.13	53.33	2.05	178.20	22.74	926.46	90.79
11_{9}	45	108.70	53.25	2.04	131.20	22.63	682.11	66.85
11_{10}	45	108.72	52.53	2.07	130.20	22.26	676.91	66.34
12_{1}	45	108.73	53.2	2.04	114.30	22.61	594.24	58.24
12_{4}	45	109.21	53.4	2.05	132.20	22.79	687.31	67.36
13_{5}	45	108.24	53.36	2.03	100.00	22.61	519.90	50.95
14_{10}	45	108.94	53.27	2.05	110.40	22.68	573.97	56.25
14_{11}	45	108.60	53.45	2.03	115.90	22.71	602.56	59.05
17_{7}	45	108.70	53.4	2.04	144.50	22.70	751.25	73.62
17_{2}	45	109.20	53.31	2.05	127.00	22.74	660.27	64.71
19_{1}	45	108.99	52.54	2.07	103.30	22.32	537.05	52.63
$_{6}$	45	108.92	53.24	2.05	108.80	22.66	565.65	55.43
24_{4}	45	109.57	53.36	2.05	114.10	22.83	593.20	58.13
24_{2}	45	108.50	53.33	2.03	120.50	22.63	626.48	61.39
23_{4}	45	110.28	52.29	2.11	109.90	22.40	571.37	55.99

Table D.1 continues

23_2	45	110.27	53.25	2.07	124.60	22.89	647.79	63.48
24_3	45	109.04	52.5	2.08	112.10	22.30	582.81	57.11
10_5	60	109.93	52.36	2.10	134.80	22.38	700.82	68.68
11_7	60	109.29	53.35	2.05	128.20	22.78	666.51	65.32
17_6	60	109.00	53.14	2.05	127.50	22.62	662.87	64.96
1_{11}	60	108.00	53.29	2.03	181.40	22.53	943.09	92.42
1_{10}	60	108.00	52.64	2.05	138.70	22.20	721.10	70.67
9_1	90	108.00	53.34	2.02	137.00	22.56	712.26	69.80
10_4	90	109.00	53.26	2.05	126.80	22.68	659.23	64.60
11_4	90	108.00	53.22	2.03	146.80	22.49	763.21	74.79
12_2	90	108.00	53.37	2.02	160.20	22.57	832.88	81.62
13_1	90	108.00	52.34	2.06	143.30	22.05	745.01	73.01
13_6	90	108.00	52.47	2.06	147.80	22.12	768.41	75.30
13_{10}	90	109.00	53.26	2.05	149.30	22.68	776.21	76.07
13_{16}	90	108.00	53.28	2.03	242.60	22.53	1261.27	123.60
Mean								72.16
Standard deviation								18.42

Table D.2 Grey andesite dry uniaxial compressive strength values

Sample No.	Angle (°)	Length(mm)	Diameter(mm)	L/D	K/N	area(cm²)	Kg/cm²	σc(MPa)
7_2	0	108.99	53.28	2.05	220.50	22.69	1146.38	112.34
7_3	0	107.85	53.34	2.02	213.30	22.53	1108.94	108.68
11_2	0	108.37	53.39	2.03	184.70	22.64	960.25	94.10
11_8	0	108.71	53.36	2.04	182.50	22.68	948.81	92.98
14_1	0	108.35	53.27	2.03	162.20	22.58	843.27	82.64
14_6	0	108.29	53.34	2.03	168.30	22.60	874.99	85.75
19_2	0	109.70	52.48	2.09	199.30	22.40	1036.16	101.54
1_1	30	109.45	53.37	2.05	223.30	22.81	1160.93	113.77
1_2	30	109.59	52.54	2.09	209.00	22.41	1086.59	106.49
1_3	30	109.52	53.32	2.05	272.30	22.80	1415.68	138.74
1_8	30	108.96	53.32	2.04	294.70	22.71	1532.14	150.15
1_4	30	108.35	53.32	2.03	217.00	22.60	1128.18	110.56
1_5	30	108.01	53.37	2.02	201.20	22.57	1046.03	102.51
2_3	30	107.52	53.45	2.01	194.60	22.53	1011.72	99.15
2_4	30	109.20	53.27	2.05	188.50	22.72	980.01	96.04
1_6	45	107.67	53.24	2.02	207.70	22.45	1079.83	105.82
2_2	45	108.53	52.54	2.07	244.80	22.24	1272.71	124.73
2_6	45	108.24	52.48	2.06	135.70	22.16	705.50	69.14
9_5	45	109.91	52.51	2.09	209.20	22.45	1087.63	106.59
14_2	45	108.79	53.27	2.04	139.70	22.65	726.30	71.18
17_3	45	109.60	52.56	2.09	212.40	22.43	1104.26	108.22

Table D.2 continues

Sample No.	Angle (°)	Length(mm)	Diameter(mm)	L/D	K/N	area(cm²)	Kg/cm²	σc(MPa)
10_8	45	109.07	53.32	2.05	192.30	22.72	999.76	97.98
19_3	45	108.87	52.51	2.07	161.50	22.28	839.64	82.28
19_4	45	109.60	53.41	2.05	169.40	22.86	880.71	86.31
13_{15}	45	109.21	53.38	2.05	170.30	22.78	885.39	86.77
13_{18}	45	108.71	53.26	2.04	157.90	22.63	820.92	80.45
24_6	45	109.84	53.34	2.06	139.70	22.86	726.30	71.18
24_7	45	109.20	53.45	2.04	109.20	22.81	567.73	55.64
13_3	45	107.67	53.34	2.02	156.60	22.50	814.16	79.79
11_5	60	108.53	53.35	2.03	213.20	22.65	1108.42	108.63
14_{14}	60	108.24	53.34	2.03	174.00	22.60	904.62	88.65
14_9	60	109.91	53.33	2.06	164.90	22.87	857.31	84.02
$13_{.9}$	60	108.79	53.2	2.04	162.50	22.62	844.83	82.79
$24_{.8}$	60	109.60	53.22	2.06	174.20	22.76	905.66	88.75
17_1	60	109.07	53.2	2.05	199.20	22.66	1035.64	101.49
10_7	90	108.87	53.26	2.04	213.00	22.66	1107.38	108.52
17_4	90	109.60	53.2	2.06	241.10	22.75	1253.47	122.84
19_5	90	109.21	53.31	2.05	148.70	22.74	773.09	75.76
17_5	90	108.71	53.41	2.04	224.50	22.71	1167.17	114.38
23_3	90	109.84	53.32	2.06	212.80	22.85	1106.34	108.42
24_5	90	110.53	53.32	2.07	188.20	22.97	978.45	95.89
24_1	90	110.53	53.37	2.07	291.10	22.99	1513.42	148.32
Mean								98.9
STD								19.9

Table D.3 Pink andesite saturated uniaxial compressive strength values

Sample No.	Angle (°)	Length(mm)	Diameter(mm)	L/D	Area(cm²)	Kg/cm²	σc(MPa)
6_5	0	109.14	52.46	2.08	22.30	450.23	44.12
6_7	0	108.59	52.5	2.07	22.23	756.97	74.18
6_8	0	109.15	52.46	2.08	22.30	678.99	66.54
5_3	0	109.17	52.41	2.08	22.28	380.57	37.30
5_4	0	109.21	52.44	2.08	22.30	416.44	40.81
4_6	0	109.71	52.32	2.10	22.32	920.74	90.23
8_5	30	110.22	53.27	2.07	22.89	408.12	40.00
16_3	30	109.07	53.24	2.05	22.68	381.09	37.35
8_3	30	110.50	53.27	2.07	22.94	411.76	40.35
8_6	30	110.09	52.48	2.10	22.47	543.81	53.29
15_3	45	108.29	53.34	2.03	22.60	385.24	37.75

Table D.3 continues

Sample No.	Angle (°)	Length(mm)	Diameter(mm)	L/D	Area(cm^2)	Kg/cm^2	σc(MPa)
15_4	45	109.70	53.33	2.06	22.84	294.78	28.89
15_6	45	109.45	53.2	2.06	22.73	294.78	28.89
15_8	45	109.59	53.22	2.06	22.76	379.01	37.14
15_9	45	109.52	53.2	2.06	22.74	395.25	38.73
15_{10}	45	108.96	53.26	2.05	22.67	549.53	53.85
15_{12}	45	108.35	53.2	2.04	22.54	379.01	37.14
15_{13}	45	108.01	53.31	2.03	22.54	316.83	31.05
16_6	45	107.52	53.41	2.01	22.51	343.65	33.68
8_2	45	110.46	52.54	2.10	22.56	295.30	28.94
8_7	45	110.30	52.51	2.10	22.52	437.23	42.85
3_6	60	108.71	53.34	2.04	22.67	722.14	70.77
3_7	60	108.35	53.35	2.03	22.62	757.49	74.23
25_3	60	109.87	52.56	2.09	22.47	669.63	65.62
18_1	60	110.09	53.32	2.06	22.90	675.87	66.24
18_2	60	109.99	52.51	2.09	22.46	771.01	75.56
4_7	90	109.17	52.53	2.08	22.34	1017.44	99.71
4_8	90	108.99	53.26	2.05	22.68	900.98	88.30
4_{10}	90	107.85	53.34	2.02	22.53	968.57	94.92
4_{11}	90	108.37	53.45	2.03	22.67	586.96	57.52
Mean							53.87
Standard deviation							21.21

Table D.4 Pink andesite dry uniaxial compressive strength values

Sample No.	Angle (°)	Length(mm)	Diameter(mm)	L/D	Area(cm^2)	Kg/cm^2	σc(MPa)
4_3	0	110.38	53.31	2.07	22.94	927.50	90.89
6_1	0	107.97	53.41	2.02	22.59	1054.87	103.38
16_{11}	0	106.36	53.27	2.00	22.24	842.75	82.59
16_{10}	0	108.34	53.24	2.03	22.56	1107.90	108.57
18_5	0	108.62	52.54	2.07	22.25	817.28	80.09
5_2	30	109.03	52.48	2.08	22.29	866.15	84.88
15_2	30	109.47	52.51	2.08	22.38	312.46	30.62
15_{14}	30	108.69	53.27	2.04	22.64	386.80	37.91
15_1	30	108.00	52.56	2.05	22.16	354.57	34.75
15_5	45	110.73	53.32	2.08	23.00	776.73	76.12
15_7	45	108.56	52.51	2.07	22.23	713.30	69.90
15_{11}	45	108.89	53.41	2.04	22.74	546.93	53.60
16_2	45	108.31	53.38	2.03	22.63	533.42	52.27
25_1	45	108.90	53.3	2.04	22.69	671.19	65.78
6_2	60	109.50	53.28	2.06	22.78	960.77	94.16
16_5	60	108.32	53.21	2.04	22.54	616.08	60.38
18_4	60	108.30	53.32	2.03	22.60	828.20	81.16
18_3	60	108.01	53.12	2.03	22.45	1114.14	109.19
6_3	60	107.52	53.33	2.02	22.47	1086.07	106.43
16_9	60	110.22	53.15	2.07	22.83	745.53	73.06
8_1	90	109.07	53.37	2.04	22.75	951.41	93.24
8_4	90	110.46	52.52	2.10	22.55	1134.94	111.22
16_4	90	110.09	53.32	2.06	22.90	1076.29	105.48
3_3	90	110.30	53.1	2.08	22.82	1174.97	115.15
3_4	90	110.50	53.21	2.08	22.91	1514.46	148.42
4_1	90	109.87	53.12	2.07	22.76	1287.79	126.20
4_2	90	110.09	53.23	2.07	22.85	1224.88	120.04
Mean							85.76
Standard deviation							28.74

Appendix E Brazilian tensile strength

Table E.1 Grey andesite dry Brazilian tensile strength values

Sample no.	Angle (°)	D(mm)	P(KN)	h(mm)	σt(Mpa)
1	90	52.68	24.62	27.52	10.81
2	0	51.53	21.47	27.28	9.72
3	45	53.34	18.25	27.29	7.98
4	90	53.17	20.35	27.85	8.75
5	45	53.54	18.84	27.89	8.03
6	90	52.63	24.12	27.67	10.54
7	0	52.34	19.70	27.45	8.73
8	45	53.48	18.04	27.42	7.83
9	90	53.12	20.01	27.45	8.74
10	0	53.38	23.28	28.06	9.89
Mean					9.10
Standard deviation					1.02

Table E.2 Grey andesite saturated Brazilian tensile strength values

Sample No.	Angle (°)	D(mm)	P(KN)	h(mm)	σt(Mpa)
11	0	53.34	20.23	27.62	8.74
12	0	53.35	17.07	27.57	7.39
13	0	53.15	15.55	27.45	6.78
14	90	53.18	17.30	27.55	7.52
15	90	53.23	18.73	27.3	8.20
16	0	53.48	18.58	27.45	8.06
17	45	53.42	14.48	27.62	6.25
18	45	53	12.96	27.5	5.66
19	45	52.32	14.05	27.3	6.26
20	90	52.37	16.80	27.15	7.52
Mean					7.24
Standard deviation					0.93

Table E.3 Pink andesite Brazilian tensile strength values

Sample no.	**Anisotropy angle**	**Physical state**	**D(mm)**	**h(mm)**	**P(KN)**	σt(Mpa)
1	45	Dry	53.2	27.51	9.92	4.31
2	0	Dry	53.25	27.3	11.70	5.12
3	90	Dry	53.11	27.27	13.24	5.82
4	0	Dry	53.27	27.6	11.80	5.11
5	45	Dry	53.44	27.7	9.85	4.24
6	0	Dry	53.08	27.3	10.88	4.78
7	90	Dry	53.41	27.5	13.16	5.70
8	90	Dry	53.28	27.4	13.47	5.87
9	45	Dry	53	27.3	9.90	4.36
Mean						5.03
Standard deviation						0.61
Sample no.	Anisotropy angle	Physical state	D(mm)	h(mm)	P(KN)	σt(Mpa)
10	45	saturated	53.57	27.25	7.98	3.48
11	0	saturated	53.68	27.6	8.89	3.82
12	0	saturated	53.74	27.7	8.90	3.81
13	45	saturated	53.64	27.4	7.84	3.39
14	45	saturated	53.59	27.6	7.72	3.32
15	0	saturated	53.6	27.5	8.96	3.87
16	90	saturated	53.91	27.1	9.18	4.00
17	90	saturated	53.3	27.3	9.90	4.33
18	90	saturated	53.75	27.15	9.79	4.27
Mean						3.81
Standard deviation						0.34

Appendix F Point load index

Table F.1 Grey andesite point-load index values

Sample No.	Angle (°)	Physical state	P(KN)	De(mm)	De(mm)²	F	Is (Mpa)	Is (50) Mpa
1	0	saturated	15.89	53.92	2907.37	1.08	5.47	5.89
2	0	saturated	14.89	53.24	2834.50	1.06	5.25	5.59
3	0	saturated	15.42	52.03	2707.12	1.04	5.70	5.93
4	0	saturated	15.65	53.09	2818.55	1.06	5.55	5.90
5	90	saturated	18.16	53.04	2813.24	1.06	6.46	6.85
6	90	saturated	18.19	53.49	2861.18	1.07	6.36	6.80
7	90	saturated	16.50	52.38	2743.66	1.05	6.01	6.30
8	90	saturated	16.98	53.3	2840.89	1.07	5.98	6.37
Mean								620
Standard deviation								0.42
Sample No.	**Angle (°)**	**Physical state**	**P(kN)**	**De(mm)**	**De(mm)²**	**F**	**Is (Mpa)**	**Is $_{(50)}$ (Mpa)**
9	0	Dry	18.69	53.27	2837.69	1.07	6.59	7.02
10	0	Dry	22.53	53.3	2840.89	1.07	7.93	8.46
11	0	Dry	18.00	52.93	2801.58	1.06	6.43	6.80
12	0	Dry	21.49	53.23	2833.43	1.06	7.58	8.07
13	90	Dry	23.56	52.55	2761.50	1.05	8.53	8.97
14	90	Dry	25.22	53.41	2852.63	1.07	8.84	9.44
15	90	Dry	23.52	53.46	2857.97	1.07	8.23	8.80
16	90	Dry	25.92	52.34	2739.48	1.05	9.46	9.90
Mean								8.43
Standard deviation								1.02

Table F.2 Pink andesite point-load index values

Sample No.	Angle (°)	Physical state	P(kN)	De(mm)	De(mm)²	F	Is (Mpa)	Is_{50}(Mpa)
1	0	Saturated	10.76	52.35	2740.5	1.0	3.93	4.11
2	0	Saturated	10.678	53.24	2834.5	1.1	3.77	4.01
3	0	Saturated	11.45	52.18	2722.8	1.0	4.21	4.39
4	0	Saturated	11.34	53.19	2829.2	1.1	4.01	4.26
5	90	Saturated	12.65	53.00	2809.0	1.1	4.50	4.77
6	90	Saturated	13.43	53.00	2809.0	1.1	4.78	5.07
7	90	Saturated	12.78	53.98	2913.8	1.1	4.39	4.74
8	90	Saturated	13.48	53.93	2908.4	1.1	4.63	5.00
Mean								4.54
Standard deviation								0.40
Sample No.	Angle (°)	Physical state	P(kN)	De(mm)	De(mm)²	F	Is (MPa)	Is_{50}(Mpa)
9	0	Dry	16.78	53.57	2869.7	1.1	5.85	6.26
10	0	Dry	16.87	52.73	2780.5	1.1	6.07	6.40
11	0	Dry	16.5	52.73	2780.5	1.1	5.93	6.26
12	0	Dry	16.98	53.33	2844.1	1.1	5.97	6.37
13	90	Dry	18.75	52.58	2764.7	1.1	6.78	7.13
14	90	Dry	18	52.95	2803.7	1.1	6.42	6.80
15	90	Dry	19.2	52.95	2803.7	1.1	6.85	7.25
16	90	Dry	19.65	52.64	2771.0	1.1	7.09	7.47
Mean								6.74
Standard deviation								0.45

Appendix G Böhme Resistance

Table G.1 Grey andesite Bohme resistance values

Sample No.	Mi(gr)	M_f(gr)	V_i (cm³)	V_f(cm³)	Δm %	ΔV cm³/50cm²
1	919.32	911.53	351.87	344.08	0.85	7.79
2	917.13	910.82	351.08	344.77	0.69	6.31
3	880.61	872.71	340.32	332.42	0.90	7.9
Mean						7.33
Standard deviation						0.72

Table G.2 Pink andesite Bohme resistance values

Sample No.	Mi(gr)	Mf (gr)	V_i (cm³	V_f(cm³)	Δm %	ΔV cm³/50cm²
1	836.78	828.19	327.64	319.05	1.03	8.59
2	840.08	830.83	327.13	317.88	1.10	9.25
3	847.96	840.96	331.2	324.2	0.83	7
Mean						8.28
Standard deviation						0.94

Appendix H Wetting and Drying

H.1 Mass loss

Table H.1.1 Grey andesite mass loss values after wetting and drying test

10.Cycle			
Sample No.	**Dry mass before test (gr)**	**Dry mass after test (gr)**	**Mass loss %**
11_1	619.69	619.49	0.03
13_{11}	572.87	572.78	0.02
13_4	565.59	565.5	0.02
13_{12}	575.73	575.73	0.00
14_5	584.48	584.39	0.02
14_3	571.76	571.61	0.03
9_3	625.88	625.88	0.00
13_{22}	574.88	574.58	0.05
		Mean	0.02
		STD	0.02
20.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
11_1	619.69	619.45	0.04
13_{11}	572.87	572.45	0.07
13_4	565.59	565.17	0.07
13_{12}	575.73	575.31	0.07
14_5	584.48	584.16	0.05
14_3	571.76	571.43	0.06
9_3	625.88	625.52	0.06
13_{22}	574.88	574.69	0.03
		Mean	0.06
		STD	0.01
30.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
11_1	619.69	619.43	0.04
13_{11}	572.87	572.5	0.06
13_4	565.59	565.14	0.08
13_{12}	575.73	575.44	0.05
14_5	584.48	584.12	0.06
14_3	571.76	571.18	0.10
9_3	625.88	625.18	0.11
13_{22}	574.88	574.75	0.02
		Mean	0.07
		STD	0.03

Table H.1.1 continues

40.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
11_1	619.69	619.26	0.07
13_{11}	572.87	572.22	0.11
13_4	565.59	565.12	0.08
13_{12}	575.73	575.47	0.05
14_5	584.48	584.09	0.07
14_3	571.76	570.95	0.14
9_3	625.88	625.55	0.05
13_{22}	574.88	574.17	0.12
		Mean	0.09
		STD	0.03
50.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
11_1	619.69	618.68	0.16
13_{11}	572.87	571.96	0.16
13_4	565.59	564.79	0.14
13_{12}	575.73	574.97	0.13
14_5	584.48	583.58	0.15
14_3	571.76	570.46	0.23
9_3	625.88	625.63	0.04
13_{22}	574.88	573.87	0.18
		Mean	0.15
		STD	0.05
60.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
11_1	619.69	618.19	0.24
13_{11}	572.87	571.52	0.24
13_4	565.59	564.26	0.24
13_{12}	575.73	574.51	0.21
14_5	584.48	583.09	0.24
14_3	571.76	570.89	0.15
9_3	625.88	625.58	0.05
13_{22}	574.88	573.52	0.24
		Mean	0.20
		STD	0.06
70.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
11_1	619.69	618.29	0.23
13_{11}	572.87	571.31	0.27
13_4	565.59	564.2	0.25
13_{12}	575.73	574.38	0.23
14_5	584.48	583.06	0.24

Table H.1.1 continues

70.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
14_3	571.76	569.78	0.35
9_3	625.88	625.01	0.14
13_{22}	574.88	573.21	0.29
		Mean	0.25
		STD	0.02
80.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
11_1	619.69	617.46	0.36
13_{11}	572.87	571.39	0.26
13_4	565.59	564.17	0.25
13_{12}	575.73	574.33	0.24
14_5	584.48	583.03	0.25
14_3	571.76	569.77	0.35
9_3	625.88	624.69	0.19
13_{22}	574.88	573.15	0.30
		Mean	0.27
		STD	0.05

H.1.2 Grey andesite mass loss values after wetting and drying test

10.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
6_6	587.75	587.66	0.02
4_9	562.44	562.21	0.04
20_2	567.84	567.55	0.05
20_3	567.69	567.54	0.03
16_8	597.73	597.58	0.03
		Mean	0.03
		STD	0.01
20.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
6_6	587.75	587.6	0.03
4_9	562.44	562.2	0.04
20_2	567.84	567.21	0.11
20_3	567.69	567.31	0.07
16_8	597.73	597.28	0.08
		Mean	0.06
		STD	0.03
30.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
6_6	587.75	587.5	0.04
4_9	562.44	561.98	0.08
20_2	567.84	567.15	0.12
20_3	567.69	567.25	0.08

Table H.1.2 continues

30.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
16_8	597.73	597.13	0.10
		Mean	0.08
		STD	0.03
40.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
20_2	567.84	566.89	0.17
20_3	567.69	567.15	0.10
16_8	597.73	597.12	0.10
		Mean	0.11
		STD	0.05
50.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
6_6	587.75	587.6	0.03
4_9	562.44	561.21	0.22
20_2	567.84	566.26	0.28
20_3	567.69	566.78	0.16
16_8	597.73	596.97	0.13
		Mean	0.16
		STD	0.09
60.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
6_6	587.75	587.26	0.08
4_9	562.44	561.16	0.23
20_2	567.84	566.08	0.31
20_3	567.69	566.16	0.27
16_8	597.73	596.63	0.18
		Mean	0.21
		STD	0.08
70.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
6_6	587.75	587.16	0.10
4_9	562.44	559.46	0.53
20_2	567.84	566.09	0.31
20_3	567.69	565.78	0.34
16_8	597.73	596.3	0.24
		Mean	0.30
		STD	0.14

H.1.2 continues

80.Cycle			
Sample No.	**Dry mass before test (gr)**	**Dry mass after test (gr)**	**Mass loss%**
6_6	587.75	587.15	0.10
4_9	562.44	559.58	0.51
20_2	567.84	565.31	0.45
20_3	567.69	565.74	0.34
16_8	597.73	596.27	0.24
		Mean	0.33
		STD	0.14

H.2 : Physical properties

Table H.2.1 Grey andesite values of physical properties after wetting and drying

0.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
11_1	386.26	626.04	619.69	1.02	2.65	25.61	25.35	2.72
13_{11}	348.3	579.37	572.87	1.13	2.81	24.60	24.32	2.89
13_4	342.17	571.88	565.59	1.11	2.74	24.42	24.15	2.82
13_{12}	348.68	582.4	575.73	1.16	2.85	24.45	24.17	2.94
14_5	354.42	591.27	584.48	1.16	2.87	24.49	24.21	2.95
14_3	345.21	578.92	571.76	1.25	3.06	24.30	24.00	3.16
9_3	380.83	632.79	625.88	1.10	2.74	24.64	24.37	2.82
13_{22}	348.12	581.23	574.88	1.10	2.72	24.46	24.19	2.80
			Mean	1.13	2.81	24.62	24.35	2.89
			STD	0.06	0.12	0.39	0.39	0.12
10.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
11_1	386.2	626.05	619.49	1.06	2.74	25.61	25.34	2.81
13_{11}	348.3	579.4	572.78	1.16	2.86	24.60	24.31	2.95
13_4	342.17	571.84	565.5	1.12	2.76	24.43	24.15	2.84
13_{12}	348.68	582.39	575.73	1.16	2.85	24.45	24.17	2.93
14_5	354.4	591.12	584.39	1.15	2.84	24.50	24.22	2.93
14_3	345.21	578.77	571.61	1.25	3.07	24.31	24.01	3.16
9_3	380.84	632.78	625.88	1.10	2.74	24.64	24.37	2.82
13_{22}	348.12	581.21	574.58	1.15	2.84	24.46	24.18	2.93
			Mean	1.14	2.84	24.62	24.34	2.92
			STD	0.05	0.10	0.38	0.39	0.11
20.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
11_1	386.23	626.01	619.45	1.06	2.74	25.61	25.34	2.81

Table H.2.1 continues

20.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
13_{11}	348.28	579.41	572.45	1.22	3.01	24.59	24.30	3.10
13_{4}	342.15	571.84	565.17	1.18	2.90	24.42	24.14	2.99
13_{12}	348.65	582.39	575.31	1.23	3.03	24.44	24.15	3.12
14_{5}	354.41	591.14	584.16	1.19	2.95	24.50	24.21	3.04
14_{3}	345.22	578.74	571.43	1.28	3.13	24.31	24.01	3.23
9_{3}	380.84	632.76	625.52	1.16	2.87	24.64	24.36	2.96
13_{22}	348.12	581.24	574.69	1.14	2.81	24.46	24.18	2.89
			Mean	1.18	2.93	24.62	24.33	3.02
			STD	0.06	0.12	0.39	0.39	0.13
30.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
11_{1}	386.18	626	619.43	1.06	2.74	25.61	25.34	2.82
13_{11}	348.2	579.5	572.5	1.22	3.03	24.58	24.28	3.12
13_{4}	342.13	571.82	565.14	1.18	2.91	24.42	24.14	3.00
13_{12}	348.7	582.44	575.44	1.22	2.99	24.44	24.15	3.09
14_{5}	354.39	591.14	584.12	1.20	2.97	24.49	24.20	3.06
14_{3}	345.22	578.74	571.18	1.32	3.24	24.31	23.99	3.35
9_{3}	380.84	632.76	625.18	1.21	3.01	24.64	24.35	3.10
13_{22}	348.08	581.28	574.75	1.14	2.80	24.45	24.18	2.88
			Mean	1.19	2.96	24.62	24.33	3.05
			STD	0.07	0.14	0.38	0.39	0.15
40.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
11_{1}	386.15	626.05	619.26	1.10	2.83	25.60	25.32	2.91
13_{11}	348.2	579.5	572.22	1.27	3.15	24.58	24.27	3.25
13_{4}	342.13	571.9	565.12	1.20	2.95	24.42	24.13	3.04
13_{12}	348.71	582.42	575.47	1.21	2.97	24.45	24.16	3.06
14_{5}	354.38	591.18	584.09	1.21	2.99	24.49	24.20	3.09
14_{3}	345.2	578.84	570.95	1.38	3.38	24.30	23.97	3.50
9_{3}	380.54	632.81	625.55	1.16	2.88	24.61	24.33	2.96
13_{22}	348.06	581.28	574.17	1.24	3.05	24.45	24.15	3.14
			Mean	1.22	3.02	24.61	24.32	3.12
			STD	0.08	0.16	0.38	0.39	0.17

Table H.2.1 continues

50.cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm	%n	γ-sat (kN/m³)	γ-dry (kN/m³)	e%
11_1	386.12	626.03	618.68	1.19	3.06	25.60	25.30	3.16
13_{11}	348.21	579.56	571.96	1.33	3.29	24.58	24.25	3.40
13_4	342.13	571.6	564.79	1.21	2.97	24.44	24.15	3.06
13_{12}	348.67	582.46	574.97	1.30	3.20	24.44	24.13	3.31
14_5	353.38	591.2	583.58	1.31	3.20	24.39	24.07	3.31
14_3	345.2	578.84	570.46	1.47	3.59	24.30	23.95	3.72
9_3	380.6	632.96	625.63	1.17	2.90	24.61	24.32	2.99
13_{22}	348.06	581.25	573.87	1.29	3.16	24.45	24.14	3.27
			Mean	1.28	3.17	24.60	24.29	3.28
			STD	0.09	0.20	0.39	0.40	0.21
60.Cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm	%n	γ-sat (kN/m³)	γ-dry (kN/m³)	e%
11_1	386.38	626.04	618.19	1.27	3.28	25.63	25.30	3.39
13_{11}	348.15	579.5	571.52	1.40	3.45	24.57	24.23	3.57
13_4	342.1	571.45	564.26	1.27	3.13	24.44	24.14	3.24
13_{12}	348.57	582.38	574.51	1.37	3.37	24.44	24.10	3.48
14_5	353.38	591.2	583.09	1.39	3.41	24.39	24.05	3.53
14_3	345.21	578.82	570.89	1.39	3.39	24.31	23.97	3.51
9_3	380.2	632.86	625.58	1.16	2.88	24.57	24.29	2.97
13_{22}	348.01	581.23	573.52	1.34	3.31	24.45	24.12	3.42
			Mean	1.32	3.28	24.60	24.28	3.39
			STD	0.08	0.18	0.40	0.40	0.19
70.Cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm	%n	γ-sat (kN/m³)	γ-dry (kN/m³)	e%
11_1	386.18	626	618.29	1.25	3.21	25.61	25.29	3.32
13_{11}	348.17	579.52	571.31	1.44	3.55	24.57	24.23	3.68
13_4	342.03	571.55	564.2	1.30	3.20	24.43	24.11	3.31
13_{12}	348.56	582.39	574.38	1.39	3.43	24.43	24.10	3.55
14_5	353.4	591.2	583.06	1.40	3.42	24.39	24.05	3.54
14_3	345.5	578.86	569.78	1.59	3.89	24.33	23.95	4.05
9_3	380.22	632.88	625.01	1.26	3.11	24.57	24.27	3.22
13_{22}	348	581.25	573.21	1.40	3.45	24.45	24.11	3.57
			Mean	1.38	3.41	24.60	24.26	3.53
			STD	0.10	0.23	0.39	0.40	0.25
80.Cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm	%n	γ-sat (kN/m³)	γ-dry (kN/m³)	e%
11_1	386.18	626.01	617.46	1.38	3.57	25.61	25.26	3.70
13_{11}	348.25	579.58	571.39	1.43	3.54	24.58	24.23	3.67
13_4	342	571.56	564.17	1.31	3.22	24.43	24.11	3.33
13_{12}	348.6	582.3	574.33	1.39	3.41	24.44	24.11	3.53

Table H.2.1 continues

14_5	353.35	591.21	583.03	1.40	3.44	24.38	24.05	3.56
14_3	345.5	578.88	569.77	1.60	3.90	24.33	23.95	4.06
9_3	380.22	632.9	624.69	1.31	3.25	24.57	24.25	3.36
13_{22}	347.98	581.25	573.15	1.41	3.47	24.44	24.10	3.60
			Mean	1.41	3.47	24.60	24.26	3.60
			STD	0.08	0.20	0.39	0.39	0.21

Table H.2.2 Pink andesite values of physical properties after wetting and drying

0.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
6_6	355.74	600.06	587.75	2.09	5.04	24.09	23.60	5.31
4_9	341.46	574.95	562.44	2.22	5.36	24.16	23.63	5.66
20_2	346.14	580.5	567.84	2.23	5.40	24.30	23.77	5.71
20_3	349.84	580.96	567.69	2.34	5.74	24.66	24.10	6.09
16_8	360.89	614.07	597.73	2.73	6.45	23.79	23.16	6.90
			Mean	2.32	5.60	24.20	23.65	5.93
			STD	0.22	0.48	0.28	0.30	0.54
10.cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
6_6	355.76	600.05	587.66	2.11	5.07	24.10	23.60	5.34
4_9	341.43	574.9	562.21	2.26	5.44	24.16	23.62	5.75
20_2	346.1	580.44	567.55	2.27	5.50	24.30	23.76	5.82
20_3	349.74	580.86	567.54	2.35	5.76	24.65	24.09	6.12
16_8	360.85	614.06	597.58	2.76	6.51	23.79	23.15	6.96
			Mean	2.35	5.66	24.20	23.64	6.00
			STD	0.22	0.48	0.28	0.30	0.54
20.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
6_6	355.8	600.01	587.6	2.11	5.08	24.10	23.60	5.35
4_9	341.38	574.89	562.2	2.26	5.43	24.15	23.62	5.75
20_2	346.05	580.4	567.21	2.33	5.63	24.30	23.74	5.96
20_3	349.34	580.96	567.31	2.41	5.89	24.61	24.03	6.26
16_8	360.82	614.02	597.28	2.80	6.61	23.79	23.14	7.08
			Mean	2.38	5.73	24.19	23.63	6.08
			STD	0.23	0.51	0.27	0.29	0.58
30.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
6_6	355.65	600	587.5	2.13	5.12	24.09	23.59	5.39
4_9	341.18	574.79	561.98	2.28	5.48	24.14	23.60	5.80
20_2	346.05	580.4	567.15	2.34	5.65	24.30	23.74	5.99
20_3	349.24	581	567.25	2.42	5.93	24.59	24.01	6.31
16_8	360.68	614	597.13	2.83	6.66	23.78	23.12	7.13
			Mean	2.40	5.77	24.18	23.61	6.13
			STD	0.23	0.51	0.27	0.29	0.58

Table H.2.2 continues

40.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
6_6	355.45	600.25	587.59	2.15	5.17	24.05	23.55	5.45
4_9	341.1	574.99	561.58	2.39	5.73	24.12	23.55	6.08
20_2	346	580.68	566.89	2.43	5.88	24.27	23.70	6.24
20_3	349.14	581.23	567.15	2.48	6.07	24.57	23.97	6.46
16_8	360.48	614.5	597.12	2.91	6.84	23.73	23.06	7.34
			Mean	2.47	5.94	24.15	23.57	6.32
			STD	0.25	0.54	0.27	0.30	0.61
50.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
6_6	355.48	600.35	587.6	2.17	5.21	24.05	23.54	5.49
4_9	341.05	574.89	561.21	2.44	5.85	24.12	23.54	6.21
20_2	346.5	580.65	566.26	2.54	6.15	24.33	23.72	6.55
20_3	349.34	582.03	566.78	2.69	6.55	24.54	23.89	7.01
16_8	360.28	614.55	596.97	2.94	6.91	23.71	23.03	7.43
			Mean	2.56	6.13	24.15	23.55	6.54
			STD	0.26	0.59	0.28	0.29	0.67
60.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
6_6	355.38	600.3	587.26	2.22	5.32	24.04	23.52	5.62
4_9	341.15	574.95	561.16	2.46	5.90	24.12	23.55	6.27
20_2	346.56	580.68	566.08	2.58	6.24	24.33	23.72	6.65
20_3	349.38	582.15	566.16	2.82	6.87	24.53	23.86	7.38
16_8	360.18	614.5	596.63	3.00	7.03	23.70	23.01	7.56
			Mean	2.62	6.27	24.15	23.53	6.70
			STD	0.27	0.63	0.28	0.29	0.71
70.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
6_6	355.4	600.65	587.16	2.30	5.50	24.03	23.49	5.82
4_9	341.18	574.98	559.46	2.77	6.64	24.13	23.47	7.11
20_2	346.46	580.89	566.09	2.61	6.31	24.31	23.69	6.74
20_3	349.23	582.1	565.78	2.88	7.01	24.52	23.83	7.54
16_8	360.16	614.4	596.3	3.04	7.12	23.71	23.01	7.66
			Mean	2.72	6.52	24.14	23.50	6.97
			STD	0.25	0.58	0.27	0.28	0.66

Table H.2.2 continues

80.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
6_6	355.35	600.68	587.15	2.30	5.52	24.02	23.48	5.84
4_9	341.08	574.95	559.58	2.75	6.57	24.12	23.47	7.03
20_2	346.4	580.93	565.31	2.76	6.66	24.30	23.65	7.14
20_3	349.2	582.16	565.74	2.90	7.05	24.51	23.82	7.58
16_8	360.12	614.4	596.27	3.04	7.13	23.70	23.00	7.68
			Mean	2.75	6.59	24.13	23.48	7.05
			STD	0.25	0.58	0.27	0.27	0.66

H.3 : P-wave velocity

Table H.3.1 Grey andesite P-wave velocity values after wetting and drying

0.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Pundit-Dry (µs)**	**Vp-Sat (m/s**	**Vp-Dry (m/s)**
11_1	109.13	20.90	21.80	5221.53	5005.96
13_{11}	110.50	21.80	22.70	5068.69	4867.73
13_4	109.93	21.40	22.20	5136.68	4951.58
13_{12}	109.99	21.50	22.30	5115.93	4932.40
14_5	110.49	21.70	23.30	5091.82	4742.17
14_3	108.92	21.90	22.70	4973.29	4798.02
9_3	110.10	20.90	23.30	5267.70	4725.11
13_{22}	109.69	21.40	23.30	5125.47	4707.51
				5125.14	4841.31
				84.55	106.87
20.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Pundit-Dry (µs)**	**Vp-Sat (m/s**	**Vp-Dry (m/s)**
11_1	109.13	20.90	21.90	5221.53	4983.11
13_{11}	110.50	21.90	23.50	5045.55	4702.02
13_4	109.93	21.40	22.80	5136.68	4821.27
13_{12}	109.99	21.60	22.90	5092.25	4803.17
14_5	110.49	21.90	24.80	5045.32	4455.34
14_3	108.92	21.90	24.90	4973.29	4374.10
9_3	110.10	20.90	23.40	5267.70	4704.91
13_{22}	109.69	21.40	23.30	5125.47	4707.51
				5113.47	4693.93
				90.49	184.17
40.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Pundit-Dry (µs)**	**Vp-Sat (m/s**	**Vp-Dry (m/s)**
11_1	109.13	20.90	21.90	5221.53	4983.11
13_{11}	110.50	21.70	23.70	5092.05	4662.34
13_4	109.93	21.40	23.30	5136.68	4717.81

Table H.3.1 continues

40.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Pundit-Dry (µs)**	**Vp-Sat (m/s**	**Vp-Dry (m/s)**
13_{12}	109.99	22.30	24.60	4932.40	4471.24
14_5	110.49	22.40	24.90	4932.70	4437.45
14_3	108.92	22.30	25.20	4884.08	4322.02
9_3	110.10	21.30	23.60	5168.78	4665.04
13_{22}	109.69	21.40	23.80	5125.47	4608.61
Mean				5061.71	4608.45
STD				118.60	189.91
60.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Pundit-Dry (µs)**	**Vp-Sat (m/s**	**Vp-Dry (m/s)**
11_1	109.13	21.90	21.90	4983.11	4983.11
13_{11}	110.50	22.30	23.80	4955.04	4642.75
13_4	109.93	21.60	23.80	5089.12	4618.70
13_{12}	109.99	21.90	24.80	5022.49	4435.18
14_5	110.49	21.50	24.80	5139.19	4455.34
14_3	108.92	21.90	25.00	4973.29	4356.60
9_3	110.10	21.40	23.50	5144.63	4684.89
13_{22}	109.69	21.40	23.80	5125.47	4608.61
			Mean	5054.04	4598.15
			std	74.28	181.50
80.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Pundit-Dry (µs)**	**Vp-Sat (m/s**	**Vp-Dry (m/s)**
11_1	109.13	21.90	22.10	4983.11	4938.01
13_{11}	110.50	22.40	23.90	4932.92	4623.33
13_4	109.93	21.80	23.90	5042.43	4599.37
13_{12}	109.99	21.90	24.80	5022.49	4435.18
14_5	110.49	22.30	24.90	4954.82	4437.45
14_3	108.92	22.30	25.20	4884.08	4322.02
9_3	110.10	21.70	23.50	5073.50	4684.89
13_{22}	109.69	22.30	23.80	4918.61	4608.61
			Mean	4976.50	4581.11
			STD	61.42	176.80

Table H.3.2 Pink andesite P-wave velocity values after wetting and drying

0.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Pundit-Dry (µs)**	**Vp-Sat (m/s**	**Vp-Dry (m/s)**
6_6	108.35	27.50	32.40	3940.00	3344.14
4_9	108.53	23.40	26.60	4638.03	4080.08
20_2	108.69	21.40	23.20	5078.97	4684.91
20_3	108.00	20.90	22.30	5167.34	4842.94
16_8	110.09	37.00	45.90	2975.41	2398.47
			Mean	4359.95	3870.11
			STD	817.26	905.18
20.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Pundit-Dry (µs)**	**Vp-Sat (m/s**	**Vp-Dry (m/s)**
6_6	108.35	28.00	33.40	3869.64	3244.01
4_9	108.53	23.40	26.60	4638.03	4080.08
20_2	108.69	21.40	23.00	5078.97	4725.65
20_3	108.00	20.40	21.80	5294.00	4954.01
16_8	110.09	39.00	46.40	2822.82	2372.63
			Mean	4340.69	3875.28
			STD	902.01	957.62
40.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Pundit-Dry (µs)**	**Vp-Sat (m/s**	**Vp-Dry (m/s)**
6_6	108.35	28.00	33.50	3869.64	3234.33
4_9	108.53	23.90	26.80	4541.00	4049.63
20_2	108.69	21.40	22.80	5078.97	4767.11
20_3	108.00	20.40	22.10	5294.00	4886.76
16_8	110.09	41.90	45.70	2627.45	2408.97
			Mean	4282.21	3869.36
			STD	962.70	939.10
	60.Cycle				
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Pundit-Dry (µs)**	**Vp-Sat (m/s**	**Vp-Dry (m/s)**
6_6	108.35	29.00	35.50	3736.21	3052.11
4_9	108.53	25.40	26.30	4272.83	4126.62
20_2	108.69	21.40	23.50	5078.97	4625.11
20_3	108.00	20.90	21.90	5167.34	4931.39
16_8	110.09	42.50	47.80	2590.35	2303.14
			Mean	4169.14	3807.67
			STD	950.26	986.63

Table H.3.2 continues

80.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Pundit-Dry (µs)**	**Vp-Sat (m/s**	**Vp-Dry (m/s)**
6_6	108.35	30.00	36.50	3611.67	2968.49
4_9	108.53	26.80	26.80	4049.63	4049.63
20_2	108.69	21.60	23.80	5031.94	4566.81
20_3	108.00	21.40	22.10	5046.61	4886.76
16_8	110.09	43.20	48.70	2548.38	2260.57
			Mean	4057.65	3746.45
			STD	938.53	987.75

Table H.4 Pink and Grey andesite uniaxial compressive strength values after wetting and drying test

Grey andesite							
Sample No.	**Length(mm)**	**Diameter(mm)**	**L/D**	**Area(cm²)**	**P(kN)**	**Kg/cm²**	**UCS(MPa)**
11_1	109.1	52.4	2.1	22.3	198.7	909.3	89.1
13_{11}	110.5	53.2	2.1	22.9	192.0	853.9	83.7
13_4	109.9	52.4	2.1	22.4	182.0	828.8	81.2
13_{12}	110.0	53.4	2.1	22.9	202.0	898.7	88.1
14_5	110.5	53.3	2.1	22.9	173.3	769.9	75.5
14_3	108.9	53.4	2.0	22.7	185.4	831.0	81.4
9_3	110.1	53.4	2.1	22.9	213.1	947.8	92.9
13_{22}	109.7	53.2	2.1	22.8	180.3	806.7	79.1
Mean							83.9
STD							5.40
Pink andesite							
Sample No.	**Length (mm)**	**Diameter (mm)**	**L/D**	**Area (cm²)**	**P(kN)**	**Kg/cm²**	**UCS(MPa)**
6_6	108.35	53.25	2.03	22.57	158.00	713.39	69.91
4_9	108.53	53.36	2.03	22.65	165.80	745.77	73.09
20_2	108.69	53.15	2.04	22.57	163.30	737.13	72.24
20_3	108.00	53.37	2.02	22.57	184.60	833.43	81.68
16_8	110.09	53.32	2.06	22.90	163.10	725.91	71.14
						Mean	73.61
						STD	4.17

Appendix I Freezing and Thawing

I.1 Mass loss

Table I.1.1 Grey andesite mass loss values after freezing and thawing

5.cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
13_{20}	557.42	557.14	0.05
13_{19}	560.51	560.42	0.02
9_{2}	623.82	623.77	0.01
13_{8}	552.47	552.27	0.04
14_{8}	577.73	577.63	0.02
14_{13}	582.97	582.6	0.06
13_{17}	578.16	578.07	0.02
14_{12}	576.92	576.61	0.05
11_{3}	594.83	594.33	0.08
		Mean	0.04
		STD	0.02
10.cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
13_{20}	557.42	557.12	0.05
13_{19}	560.51	560.35	0.03
9_{2}	623.82	623.61	0.03
13_{8}	552.47	552.15	0.06
14_{8}	577.73	577.56	0.03
14_{13}	582.97	582.34	0.11
13_{17}	578.16	577.89	0.05
14_{12}	576.92	576.44	0.08
11_{3}	594.83	594.18	0.11
		Mean	0.06
		STD	0.03
15.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
13_{20}	557.42	557.08	0.06
13_{19}	560.51	560.31	0.04
9_{2}	623.82	623.07	0.12
13_{8}	552.47	552.01	0.08
14_{8}	577.73	577.1	0.11
14_{13}	582.97	582.44	0.09
13_{17}	578.16	577.28	0.15
14_{12}	576.92	576.07	0.15
11_{3}	594.83	594.04	0.13
		Mean	0.10
		STD	0.04

Table I.1.1 continues

20.cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
13_{20}	557.42	556.94	0.09
13_{19}	560.51	559.97	0.10
9_{2}	623.82	622.91	0.15
13_{8}	552.47	551.9	0.10
14_{8}	577.73	576.91	0.14
14_{13}	582.97	582.64	0.06
13_{17}	578.16	577.32	0.15
14_{12}	576.92	576.06	0.15
11_{3}	594.83	594.06	0.13
		Mean	0.12
		STD	0.03
25.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
13_{20}	557.42	556.67	0.13
13_{19}	560.51	559.64	0.16
9_{2}	623.82	623.07	0.12
13_{8}	552.47	551.8	0.12
14_{8}	577.73	576.88	0.15
14_{13}	582.97	582.16	0.14
13_{17}	578.16	577.25	0.16
14_{12}	576.92	575.95	0.17
11_{3}	594.83	594.04	0.13
		Mean	0.14
		STD	0.02
30.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
13_{20}	557.42	556.41	0.18
13_{19}	560.51	559.46	0.19
9_{2}	623.82	622.91	0.15
13_{8}	552.47	551.61	0.16
14_{8}	577.73	576.27	0.25
14_{13}	582.97	582.13	0.14
13_{17}	578.16	577.46	0.12
14_{12}	576.92	575.83	0.19
11_{3}	594.83	593.81	0.17
		Mean	0.17
		STD	0.04

Table I.1.1 continues

35.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
13_{20}	557.42	556.23	0.21
13_{19}	560.51	559.35	0.21
9_{2}	623.82	622.69	0.18
13_{8}	552.47	551.44	0.19
14_{8}	577.73	576.5	0.21
14_{13}	582.97	581.71	0.22
13_{17}	578.16	577.2	0.17
14_{12}	576.92	575.78	0.20
11_{3}	594.83	593.78	0.18
		Mean	0.20
		STD	0.02
40.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
13_{20}	557.42	556.16	0.23
13_{19}	560.51	559.16	0.24
9_{2}	623.82	622.31	0.24
13_{8}	552.47	551.09	0.25
14_{8}	577.73	576.27	0.25
14_{13}	582.97	581.66	0.22
13_{17}	578.16	576.68	0.26
14_{12}	576.92	575.59	0.23
11_{3}	594.83	593.37	0.25
		Mean	0.24
		STD	0.01
45.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
13_{20}	557.42	555.68	0.31
13_{19}	560.51	558.35	0.39
9_{2}	623.82	622.05	0.28
13_{8}	552.47	550.64	0.33
14_{8}	577.73	575.84	0.33
14_{13}	582.97	580.39	0.44
13_{17}	578.16	576.09	0.36
14_{12}	576.92	575.38	0.27
11_{3}	594.83	592.93	0.32
		Mean	0.34
		STD	0.05

Table I.1.2 Pink andesite mass loss values after freezing and thawing

5.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
3_2	587.72	587.35	0.06
6_4	590.4	590.31	0.02
4_5	576.37	576.17	0.03
3_1	588.05	587.82	0.04
20_4	571.09	570.67	0.07
10_6	596.7	596.11	0.10
16_1	614.98	614.65	0.05
		Mean	0.05
		STD	0.03
10.cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
3_2	587.72	587.13	0.10
6_4	590.4	589.61	0.13
4_5	576.37	576.08	0.05
3_1	588.05	587.49	0.10
20_4	571.09	570.53	0.10
10_6	596.7	595.76	0.16
16_1	614.98	614.01	0.16
		Mean	0.11
		STD	0.03
15.cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
3_2	587.72	586.93	0.13
6_4	590.4	589.41	0.17
4_5	576.37	575.78	0.10
3_1	588.05	587.19	0.15
20_4	571.09	570.23	0.15
10_6	596.7	595.36	0.22
16_1	614.98	613.68	0.21
		Mean	0.16
		STD	0.04
20.cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
3_2	587.72	586.83	0.15
6_4	590.4	589.22	0.20
4_5	576.37	575.62	0.13
3_1	588.05	586.65	0.24
20_4	571.09	569.91	0.21
10_6	596.7	595.59	0.19
16_1	614.98	613.66	0.21
		Mean	0.19
		STD	0.03

Table I.1.2 continues

25.cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
3_2	587.72	586.82	0.15
6_4	590.4	588.62	0.30
4_5	576.37	575.27	0.19
3_1	588.05	586.77	0.22
20_4	571.09	569.84	0.22
10_6	596.7	595.3	0.23
16_1	614.98	613.34	0.27
		Mean	0.23
		STD	0.04
30.cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
3_2	587.72	586.63	0.19
6_4	590.4	588.42	0.34
4_5	576.37	575.1	0.22
3_1	588.05	586.47	0.27
20_4	571.09	569.64	0.25
10_6	596.7	594.63	0.35
16_1	614.98	613.14	0.30
		Mean	0.27
		STD	0.05
35.cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
3_2	587.72	586.39	0.23
6_4	590.4	588.4	0.34
4_5	576.37	574.8	0.27
3_1	588.05	585.56	0.42
20_4	571.09	568.98	0.37
10_6	596.7	594.09	0.44
16_1	614.98	612.74	0.36
		Mean	0.35
		STD	0.07
40.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
3_2	587.72	585.32	0.41
6_4	590.4	587.17	0.55
4_5	576.37	574.21	0.37
3_1	588.05	585.89	0.37
20_4	571.09	569.65	0.25
10_6	596.7	593.97	0.46
16_1	614.98	612.22	0.45
		Mean	0.41
		STD	0.08

Table I.1.2 continues

45.Cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
3_2	587.72	584.34	0.58
6_4	590.4	588.21	0.37
4_5	576.37	573.25	0.54
3_1	588.05	584.85	0.54
20_4	571.09	568.3	0.49
10_6	596.7	593.89	0.47
16_1	614.98	612.3	0.44
		Mean	0.49
		STD	0.07

I.2 Physical Properties

Table I.2.1 Grey andesite values of physical properties after freezing and thawing test

0.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
13_{20}	334.34	564.86	557.42	1.33	3.23	24.04	23.72	3.34
13_{19}	335.88	569.71	560.51	1.64	3.93	23.90	23.52	4.10
9_2	398.56	630.06	623.82	1.00	2.70	26.70	26.43	2.77
13_8	330.09	564.93	552.47	2.26	5.31	23.60	23.08	5.60
14_8	355.13	585.08	577.73	1.27	3.20	24.96	24.65	3.30
14_{13}	350.89	591.86	582.97	1.52	3.69	24.09	23.73	3.83
13_{17}	347.12	588.82	578.16	1.84	4.41	23.90	23.47	4.61
14_{12}	346.13	586.08	576.92	1.59	3.82	23.96	23.59	3.97
11_3	368.54	601.89	594.83	1.19	3.03	25.30	25.01	3.12
			Mean	1.52	3.70	24.50	24.13	3.85
			STD	0.36	0.75	0.94	0.99	0.82
5.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
13_{20}	334.64	566.89	557.12	1.45	3.50	24.05	23.70	3.63
13_{19}	336.28	570.06	560.35	1.61	3.87	23.99	23.61	4.03
9_2	388.25	631.75	623.61	1.17	3.01	25.54	25.25	3.10
13_8	332.35	564.12	552.15	2.27	5.47	24.14	23.61	5.79
14_8	357.56	587.57	577.56	1.50	3.78	25.05	24.68	3.93
14_{13}	356.41	591.38	582.34	1.39	3.37	24.16	23.83	3.49
13_{17}	346.83	587.79	577.89	1.61	3.90	24.14	23.76	4.06
14_{12}	346.87	585.7	576.44	1.65	3.97	24.04	23.65	4.14
11_3	368.96	600.25	594.18	1.11	2.83	25.38	25.10	2.91
Mean				1.53	3.75	24.50	24.13	3.90
STD				0.32	0.72	0.60	0.64	0.78

Table I.2.1 continues

10.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
13_{20}	334.41	566.89	557.12	1.75	4.20	23.92	23.51	4.39
13_{19}	336.28	570.06	560.35	1.73	4.15	23.92	23.51	4.33
9_{2}	388.25	631.75	623.61	1.31	3.34	25.45	25.12	3.46
13_{8}	332.35	564.12	552.15	2.17	5.16	23.88	23.37	5.45
14_{8}	357.56	587.57	577.56	1.73	4.35	25.06	24.63	4.55
14_{13}	356.41	591.38	582.34	1.55	3.85	24.69	24.31	4.00
13_{17}	346.83	587.79	577.89	1.71	4.11	23.93	23.53	4.28
14_{12}	346.87	585.7	576.44	1.61	3.88	24.06	23.68	4.03
11_{3}	368.96	600.25	594.18	1.02	2.62	25.46	25.20	2.70
Mean				1.62	3.96	24.49	24.10	4.13
STD				0.30	0.66	0.65	0.69	0.71
15.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
13_{20}	334.66	568.25	557.08	2.01	4.78	23.86	23.40	5.02
13_{19}	336.62	569.6	560.31	1.66	3.99	23.98	23.59	4.15
9_{2}	388.34	630.88	623.07	1.25	3.22	25.52	25.20	3.33
13_{8}	332.93	563.86	552.01	2.15	5.13	23.95	23.45	5.41
14_{8}	355.93	586.44	577.1	1.62	4.05	24.96	24.56	4.22
14_{13}	356.21	591.01	582.44	1.47	3.65	24.69	24.33	3.79
13_{17}	346.8	587.6	577.28	1.79	4.29	23.94	23.52	4.48
14_{12}	346.57	585.23	576.07	1.59	3.84	24.06	23.68	3.99
11_{3}	367.37	601.37	594.04	1.23	3.13	25.21	24.90	3.23
Mean				1.64	4.01	24.46	24.07	4.18
STD				0.29	0.62	0.60	0.65	0.68
20.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
13_{20}	334.84	565.97	556.94	1.62	3.91	24.02	23.64	4.07
13_{19}	336.73	569.7	559.97	1.74	4.18	23.99	23.58	4.36
9_{2}	388.18	633.65	622.91	1.72	4.38	25.32	24.89	4.58
13_{8}	332.98	562.98	551.9	2.01	4.82	24.01	23.54	5.06
14_{8}	355.8	586.5	576.91	1.66	4.16	24.94	24.53	4.34
14_{13}	353.22	591.17	582.64	1.46	3.58	24.37	24.02	3.72
13_{17}	346.88	587.76	577.32	1.81	4.33	23.94	23.51	4.53
14_{12}	346.44	585.23	576.06	1.59	3.84	24.04	23.67	3.99
11_{3}	368.74	601.03	594.06	1.17	3.00	25.38	25.09	3.09
Mean				1.64	4.02	24.45	24.05	4.19
STD				0.22	0.49	0.57	0.59	0.53

Table I.2.1 continues

25.Cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm	%n	γ-sat (kN/m³)	γ-dry (kN/m³)	e%
13_{20}	334.77	565.12	556.67	1.52	3.67	24.07	23.71	3.81
13_{19}	336.74	569.97	559.64	1.85	4.43	23.97	23.54	4.63
9_2	388.11	630.86	623.07	1.25	3.21	25.49	25.18	3.32
13_8	333.85	564.33	551.8	2.27	5.44	24.02	23.49	5.75
14_8	356.87	586.93	576.88	1.74	4.37	25.03	24.60	4.57
14_{13}	354.23	591.62	582.16	1.62	3.99	24.45	24.06	4.15
13_{17}	345.88	587.98	577.25	1.86	4.43	23.83	23.39	4.64
14_{12}	345.28	585.46	575.95	1.65	3.96	23.91	23.52	4.12
11_3	367.53	601.08	594.04	1.19	3.01	25.25	24.95	3.11
			Mean	1.66	4.06	24.45	24.05	4.23
			STD	0.31	0.69	0.61	0.65	0.75
30.Cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm	%n	γ-sat (kN/m³)	γ-dry (kN/m³)	e%
13_{20}	334.52	565.22	556.41	1.58	3.82	24.03	23.66	3.97
13_{19}	336.44	567.71	559.46	1.47	3.57	24.08	23.73	3.70
9_2	388.25	631.46	622.91	1.37	3.52	25.47	25.13	3.64
13_8	331.9	560.95	551.61	1.69	4.08	24.02	23.62	4.25
14_8	355.42	587.18	576.27	1.89	4.71	24.85	24.39	4.94
14_{13}	353.94	591.88	582.13	1.67	4.10	24.40	24.00	4.27
13_{17}	346.58	588.79	577.46	1.96	4.68	23.85	23.39	4.91
14_{12}	346.41	587.31	575.83	1.99	4.77	23.92	23.45	5.00
11_3	367.51	602.45	593.81	1.46	3.68	25.16	24.79	3.82
			Mean	1.68	4.10	24.42	24.02	4.28
			STD	0.22	0.47	0.56	0.58	0.52
35.Cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm	%n	γ-sat (kN/m³)	γ-dry (kN/m³)	e%
13_{20}	334.39	565.8	556.23	1.72	4.14	23.99	23.58	4.31
13_{19}	336.35	570.34	559.35	1.96	4.70	23.91	23.45	4.93
9_2	388.56	631.59	622.69	1.43	3.66	25.49	25.14	3.80
13_8	333.29	560.39	551.44	1.62	3.94	24.21	23.82	4.10
14_8	354.93	587.8	576.5	1.96	4.85	24.76	24.29	5.10
14_{13}	355.38	593.57	581.71	2.04	4.98	24.45	23.96	5.24
13_{17}	346.68	588.07	577.2	1.88	4.50	23.90	23.46	4.72
14_{12}	347.3	586.94	575.78	1.94	4.66	24.03	23.57	4.88
11_3	368.18	603.71	593.78	1.67	4.22	25.14	24.73	4.40
			Mean	1.80	4.40	24.43	24.00	4.61
			STD	0.19	0.42	0.55	0.57	0.46

Table I.2.1 continues

40.Cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm	%n	γ-sat (kN/m³)	γ-dry (kN/m³)	e%
13_{20}	334.25	569.46	556.16	2.39	5.65	23.75	23.20	5.99
13_{19}	336.19	570.08	559.16	1.95	4.67	23.91	23.45	4.90
9_{2}	388.57	631.11	622.31	1.41	3.63	25.53	25.17	3.76
13_{8}	333.62	564.51	551.09	2.44	5.81	23.98	23.41	6.17
14_{8}	354.05	586.57	576.27	1.79	4.43	24.75	24.31	4.64
14_{13}	356.58	591.34	581.66	1.66	4.12	24.71	24.31	4.30
13_{17}	346.37	588.09	576.68	1.98	4.72	23.87	23.40	4.95
14_{12}	346.58	585.6	575.59	1.74	4.19	24.03	23.62	4.37
11_{3}	368.21	601.64	593.37	1.39	3.54	25.28	24.94	3.67
			Mean	1.86	4.53	24.42	23.98	4.75
			STD	0.35	0.75	0.62	0.68	0.82
45. Cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm	%n	γ-sat (kN/m³)	γ-dry (kN/m³)	e%
13_{20}	336.39	566.97	555.68	2.03	4.90	24.12	23.64	5.15
13_{19}	337.37	571.2	558.35	2.30	5.50	23.96	23.42	5.82
9_{2}	389.19	631.79	622.05	1.57	4.01	25.55	25.15	4.18
13_{8}	329.84	567.02	550.64	2.97	6.91	23.45	22.78	7.42
14_{8}	353.9	582.58	575.84	1.17	2.95	24.99	24.70	3.04
14_{13}	353.26	591.86	580.39	1.98	4.81	24.33	23.86	5.05
13_{17}	347.12	588.85	576.09	2.21	5.28	23.90	23.38	5.57
14_{12}	346.9	580.13	575.38	0.83	2.04	24.40	24.20	2.08
11_{3}	367.23	604.33	592.93	1.92	4.81	25.00	24.53	5.05
			Mean	1.89	4.58	24.41	23.96	4.82
			STD	0.60	1.35	0.62	0.71	1.48

Table I.2.2 Grey andesite values of physical properties after freezing and thawing test

0.Cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm	%n	γ-sat (kN/m³)	γ-dry (kN/m³)	e%
32	358.15	605.20	587.72	2.97	7.08	24.03	23.34	7.61
64	364.38	606.74	590.40	2.77	6.74	24.56	23.90	7.23
45	353.61	590.05	576.37	2.37	5.79	24.48	23.91	6.14
31	357.15	602.00	588.05	2.37	5.70	24.12	23.56	6.04
204	347.84	580.11	571.09	1.58	3.88	24.50	24.12	4.04
106	369.55	603.28	596.70	1.10	2.82	25.32	25.04	2.90
161	363.37	625.16	614.98	1.66	3.89	23.43	23.05	4.05
				2.12	5.13	24.35	23.85	5.43
				0.63	1.49	0.54	0.60	1.65

Table I.2.2 continues

5.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
32	358.05	602.77	587.35	2.63	6.30	24.16	23.54	6.72
64	364.48	605.84	590.31	2.63	6.43	24.62	23.99	6.88
45	352.61	589.94	576.17	2.39	5.80	24.39	23.82	6.16
31	357.15	603.03	587.82	2.59	6.19	24.06	23.45	6.59
204	346.84	576.79	570.67	1.07	2.66	24.61	24.35	2.73
106	369.55	605.2	596.11	1.52	3.86	25.19	24.82	4.01
161	363.50	624.92	614.65	1.67	3.93	23.45	23.07	4.09
			Mean	2.07	5.02	24.35	23.86	5.31
			STD	0.59	1.40	0.50	0.54	1.54
10.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
32	362.87	601.81	588.03	2.34	5.77	24.71	24.14	6.12
64	366.29	605.83	589.61	2.75	6.77	24.81	24.15	7.26
45	355.04	592.94	577.25	2.72	6.60	24.45	23.80	7.06
31	362.07	603.91	587.49	2.79	6.79	24.50	23.83	7.28
204	341.48	577.26	571.13	1.07	2.60	24.02	23.76	2.67
106	362.4	605.21	595.76	1.59	3.89	24.45	24.07	4.05
161	363.04	624.91	614.01	1.78	4.16	23.41	23.00	4.34
			Mean	2.15	5.23	24.34	23.82	5.54
			STD	0.63	1.55	0.44	0.37	1.71
15.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
32	362.66	601.61	586.93	2.50	6.14	24.70	24.10	6.55
64	365.1	605.63	589.41	2.75	6.74	24.70	24.04	7.23
45	354.78	592.72	575.78	2.94	7.12	24.44	23.74	7.67
31	361.89	602.9	587.19	2.68	6.52	24.54	23.90	6.97
204	341.12	577.02	570.23	1.19	2.88	24.00	23.71	2.96
106	361.31	605.21	595.36	1.65	4.04	24.34	23.95	4.21
161	362.89	624.81	613.68	1.81	4.25	23.40	22.98	4.44
			Mean	2.22	5.38	24.30	23.77	5.72
			STD	0.61	1.52	0.43	0.35	1.54

Table I.2.2 continues

20.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
32	362.9	601.96	586.83	2.58	6.33	24.70	24.08	6.76
64	364.18	605.88	589.22	2.83	6.89	24.59	23.91	7.40
45	354.81	592.65	575.62	2.96	7.16	24.44	23.74	7.71
31	362.11	603.27	586.65	2.83	6.89	24.54	23.86	7.40
204	341.28	577.23	569.91	1.28	3.10	24.00	23.69	3.20
106	361.37	605.29	595.59	1.63	3.98	24.34	23.95	4.14
161	363.05	625.13	613.66	1.87	4.38	23.40	22.97	4.58
			Mean	2.28	5.53	24.29	23.75	5.88
			STD	0.63	1.54	0.42	0.34	1.72
25.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
32	362.5	602.13	586.82	2.61	6.39	24.65	24.02	6.83
64	364.01	605.97	588.62	2.95	7.17	24.57	23.86	7.72
45	354.16	592.49	575.27	2.99	7.23	24.39	23.68	7.79
31	361.82	603.11	586.77	2.78	6.77	24.52	23.86	7.26
204	341.25	577.51	569.84	1.35	3.25	23.98	23.66	3.36
106	361.31	605.43	595.3	1.70	4.15	24.33	23.92	4.33
161	362.91	625.16	613.34	1.93	4.51	23.39	22.94	4.72
			Mean	2.33	5.64	24.26	23.71	6.00
			STD	0.61	1.51	0.41	0.33	1.68
30.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
32	362.95	602.14	586.63	2.64	6.48	24.70	24.06	6.93
64	362.45	606.34	588.42	3.05	7.35	24.39	23.67	7.93
45	355.85	593.89	575.1	3.27	7.89	24.48	23.70	8.57
31	362.25	603.42	586.47	2.89	7.03	24.55	23.86	7.56
204	341.72	578	569.64	1.47	3.54	24.00	23.65	3.67
106	361.48	605.44	594.63	1.82	4.43	24.35	23.91	4.64
161	363.08	625.29	613.14	1.98	4.63	23.39	22.94	4.86
			Mean	2.44	5.91	24.26	23.68	6.31
			STD	0.64	1.56	0.41	0.33	1.76

Table I.2.2 continues

35.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
32	363	602.35	586.39	2.72	6.67	24.69	24.03	7.14
64	361.5	606.31	588.4	3.04	7.32	24.30	23.58	7.89
45	355.5	593.56	574.8	3.26	7.88	24.46	23.69	8.55
31	362.23	603.46	585.56	3.06	7.42	24.54	23.81	8.02
204	341.72	577.89	568.98	1.57	3.77	24.00	23.63	3.92
106	361.39	606.42	594.09	2.08	5.03	24.28	23.78	5.30
161	363.07	625.3	612.74	2.05	4.79	23.39	22.92	5.03
				2.54	6.13	24.24	23.64	6.55
				0.60	1.46	0.40	0.32	1.65
40.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
32	363.14	602	585.32	2.85	6.98	24.72	24.04	7.51
64	361.55	606.21	587.17	3.24	7.78	24.31	23.54	8.44
45	355.77	593.51	574.21	3.36	8.12	24.49	23.69	8.84
31	361.33	603.24	585.89	2.96	7.17	24.46	23.76	7.73
204	341.84	577.61	569.65	1.40	3.38	24.03	23.70	3.49
106	359.4	605.14	593.97	1.88	4.55	24.16	23.71	4.76
161	363.12	625.18	612.22	2.12	4.95	23.40	22.92	5.20
				2.54	6.13	24.23	23.62	6.57
				0.69	1.69	0.40	0.32	1.91
45.Cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
32	363.66	602.87	584.34	3.17	7.75	24.72	23.96	8.40
64	361.93	606.69	588.21	3.14	7.55	24.32	23.58	8.17
45	355.91	598.75	573.25	4.45	10.50	24.19	23.16	11.73
31	362.88	603.09	584.85	3.12	7.59	24.63	23.88	8.22
204	342.47	577.75	568.3	1.66	4.02	24.09	23.70	4.18
106	359.53	605.08	593.89	1.88	4.56	24.17	23.73	4.77
161	363.18	623.44	612.3	1.82	4.28	23.50	23.08	4.47
				2.75	6.61	24.23	23.58	7.13
				0.94	2.22	0.37	0.32	2.57

I.3 P-wave velocity

Table I.3.1 Grey andesite P-wave velocity values after freezing and thawing

0.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Pundit-Dry (µs)**	**Vp-Sat (m/s**	**Vp-Dry (m/s)**
13_{20}	109.41	23.94	23.60	4635.80	4569.53
13_{19}	109.84	23.88	23.50	4673.83	4598.81
9_{2}	109.28	25.35	25.03	4366.25	4310.34
13_{8}	109.89	23.50	23.04	4770.53	4675.29
14_{8}	108.65	23.90	23.53	4617.73	4545.04
14_{13}	109.10	24.06	23.73	4597.80	4534.90
13_{17}	110.06	23.84	23.43	4696.68	4616.64
14_{12}	108.65	23.93	23.60	4604.29	4540.51
11_{3}	108.72	25.27	24.99	4349.91	4302.35
Mean				4590.31	4521.49
STD				134.10	122.34
15.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Vp-Sat (m/s)**	**Pundit-Dry (µs)**	**Vp-Dry (m/s)**
13_{20}	109.41	23.70	23.19	4717.85	4615.75
13_{19}	109.84	23.88	23.45	4683.90	4599.29
9_{2}	109.28	25.52	25.21	4335.59	4282.61
13_{8}	109.89	23.55	23.03	4772.69	4667.31
14_{8}	108.65	23.36	22.56	4814.96	4651.56
14_{13}	109.10	24.08	23.71	4601.87	4531.24
13_{17}	110.06	23.83	23.42	4700.13	4617.59
14_{12}	108.65	23.96	23.56	4611.46	4535.34
11_{3}	108.72	25.21	24.92	4362.82	4312.26
Mean				4622.36	4534.77
STD				159.44	134.12

Table I.3.1 continues

30.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Vp-Sat (m/s)**	**Pundit-Dry (µs)**	**Vp-Dry (m/s)**
13_{20}	109.41	24.03	23.63	4630.07	4552.17
13_{19}	109.84	24.08	23.62	4649.69	4561.15
9_{2}	109.28	25.54	25.21	4335.46	4279.03
13_{8}	109.89	23.82	23.43	4690.46	4614.03
14_{8}	108.65	23.93	23.48	4627.00	4541.02
14_{13}	109.10	24.10	23.70	4603.04	4527.21
13_{17}	110.06	23.85	23.39	4705.66	4615.11
14_{12}	108.65	23.92	23.42	4639.67	4542.66
11_{3}	108.72	25.27	24.91	4364.17	4301.58
Mean				4582.80	4503.77
STD				128.22	117.86
45.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Vp-Sat (m/s)**	**Pundit-Dry (µs)**	**Vp-Dry (m/s)**
13_{20}	109.41	24.08	23.67	4622.92	4543.77
13_{19}	109.84	24.02	23.80	4615.74	4571.86
9_{2}	109.28	25.55	25.15	4345.66	4277.50
13_{8}	109.89	23.61	23.00	4777.51	4654.44
14_{8}	108.65	24.25	23.74	4577.18	4480.31
14_{13}	109.10	24.13	23.70	4603.27	4520.98
13_{17}	110.06	24.01	23.49	4685.64	4582.96
14_{12}	108.65	24.40	24.05	4518.27	4452.46
11_{3}	108.72	25.30	24.75	4392.30	4296.37
Mean				4570.94	4486.74
STD				127.82	120.32

Table I.3.2 Pink andesite P-wave velocity values after freezing and thawing

0.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Vp-Sat (m/s)**	**Pundit-Dry (µs)**	**Vp-Dry (m/s)**
3_2	108.29	24.71	24.13	4382.59	4487.90
6_4	109.70	24.46	23.83	4485.06	4603.05
4_5	109.45	24.33	23.62	4498.60	4632.80
3_1	109.59	24.54	23.97	4465.42	4572.40
20_4	110.73	24.01	23.35	4611.54	4741.59
10_6	108.46	25.50	25.08	4252.96	4324.21
16_1	110.22	25.34	24.90	4349.76	4426.03
Mean				4435.13	4541.14
STD				108.10	129.03
15.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Vp-Sat (m/s)**	**Pundit-Dry (µs)**	**Vp-Dry (m/s)**
3_2	108.29	25.64	24.98	4223.97	4334.39
6_4	109.70	25.00	23.90	4388.77	4590.29
4_5	109.45	25.37	24.88	4314.68	4399.50
3_1	109.59	24.70	24.05	4437.15	4557.44
20_4	110.73	24.54	23.86	4512.18	4640.88
10_6	108.46	25.01	24.18	4336.22	4486.23
16_1	110.22	25.44	24.73	4332.93	4456.07
Mean				4363.70	4494.97
STD				85.94	100.55
30.Cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Vp-Sat (m/s)**	**Pundit-Dry (µs)**	**Vp-Dry (m/s)**
3_2	108.29	25.90	25.01	4181.66	4330.43
6_4	109.70	25.60	24.85	4284.49	4414.94
4_5	109.45	25.58	24.75	4279.35	4422.20
3_1	109.59	24.95	24.83	4393.34	4414.21
20_4	110.73	25.00	23.99	4429.60	4616.59
10_6	108.46	25.36	24.21	4276.27	4480.15
16_1	110.22	25.63	24.98	4301.08	4412.32
Mean				4306.54	4441.55
STD				76.01	82.08

Table I.3.2 continues

45.Cycle					
Sample No.	Length(mm)	Pundit-Sat (µs)	Vp-Sat (m/s)	Pundit-Dry (µs)	Vp-Dry (m/s)
3_2	108.29	26.02	25.05	4161.11	4323.58
6_4	109.70	25.93	24.90	4231.34	4406.20
4_5	109.45	24.99	24.81	4379.96	4410.78
3_1	109.59	25.93	24.94	4227.22	4393.85
20_4	110.73	24.97	23.99	4433.86	4615.36
10_6	108.46	25.93	25.07	4183.51	4326.80
16_1	110.22	25.71	24.34	4287.76	4528.22
Mean				4272.11	4429.26
STD				94.03	98.72

Table I.4 Pink and grey andesite uniaxial compressive strength values after freezing and thawing test

Grey andesite							
Sample No.	Length(mm)	Diameter(mm)	L/D	Area(cm²)	P(kN)	Kg/cm²	UCS(MPa)
13_{20}	109.41	52.56	2.08	22.39	162.60	739.88	72.51
13_{19}	109.84	52.62	2.09	22.50	179.30	812.20	79.60
9_2	109.28	53.3	2.05	22.75	164.20	735.49	72.08
13_8	109.89	52.64	2.09	22.51	160.20	725.06	71.06
14_8	108.65	53.32	2.04	22.65	167.10	751.65	73.66
14_{13}	109.10	53.32	2.05	22.73	162.60	728.96	71.44
13_{17}	110.06	53.07	2.07	22.76	171.30	766.88	75.15
14_{12}	108.65	53.32	2.04	22.65	169.40	762.00	74.68
11_3	108.72	53.25	2.04	22.63	164.60	741.17	72.64
Mean							73.64
STD							2.47
Pink andesite							
Sample No.	Length(mm)	Diameter(mm)	L/D	Area(cm²)	P(kN)	Kg/cm²	UCS(MPa)
3_2	108.29	53.34	2.03	22.60	162.90	734.37	71.97
6_4	109.70	53.33	2.06	22.84	156.80	699.71	68.57
4_5	109.45	53.20	2.06	22.73	154.50	692.75	67.89
3_1	109.59	53.22	2.06	22.76	156.70	701.54	68.75
20_4	110.73	52.52	2.11	22.59	157.60	710.87	69.66
10_6	108.46	53.30	2.03	22.61	157.70	710.66	69.64
16_1	110.22	53.27	2.07	22.89	153.60	683.75	67.01
Mean							69.07
STD							1.47

Appendix J Sodium Sulphate Salt Crystallization

J.1 Mass loss

Table J.1.1 Grey andesite mass loss values after sodium sulphate soundness test

5.cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
22_5	600.76	599.85	0.15
22_1	608.98	608.05	0.15
13_7	570.55	569.62	0.16
13_{13}	560.45	558.71	0.31
22_2	598.68	596.22	0.41
Mean			0.24
Standard deviation			0.11
10.cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
22_5	600.76	599.41	0.23
22_1	608.98	607.57	0.23
13_7	570.55	565.54	0.89
13_{13}	560.45	555.47	0.90
22_2	598.68	595.89	0.47
Mean			0.54
Standard deviation			0.23
15.cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
22_5	600.76	598.23	0.42
22_1	608.98	605.67	0.55
13_7	570.55	565.38	0.91
13_{13}	560.45	554.99	0.98
22_2	598.68	595.44	0.54
Mean			0.68
Standard deviation			0.22

Table J.1.2 Pink andesite mass loss values after sodium sulphate soundness test

5.cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
3_5	585.96	581.70	0.73
20_1	594.28	593.20	0.18
21_2	587.38	585.98	0.24
5_1	585.12	582.96	0.37
21_1	587.38	582.99	0.75
			0.45
			0.24
10.cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
3_5	585.96	580.31	0.96
20_1	594.28	591.67	0.44
21_2	587.38	582.22	0.88
5_1	585.12	578.07	1.20
21_1	587.38	580.11	1.24
			0.94
			0.29
15.cycle			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss%**
3_5	585.96	579.02	1.18
20_1	594.28	588.15	1.03
21_2	587.38	580.83	1.12
5_1	585.12	575.97	1.56
21_1	587.38	580.27	1.21
			1.22
			0.18

J.2 Physical Properties

Table J.2.1 Grey andesite values of physical properties after sodium sulphate soundness test

0.cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm%**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
22_5	365.49	606.39	600.76	0.94	2.34	24.69	24.46	2.39
22_1	369.14	614.2	608.98	0.86	2.13	24.59	24.38	2.18
13_7	347.3	576.3	570.55	1.01	2.51	24.69	24.44	2.58
13_{13}	342.56	565.34	560.45	0.87	2.19	24.89	24.68	2.24
22_2	363.97	607.01	598.68	1.39	3.43	24.50	24.16	3.55
Mean				1.01	2.52	24.67	24.43	2.59
Standard deviation				0.20	0.47	0.13	0.17	0.50
5.cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm%**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
22_5	364.04	604.71	599.85	0.81	2.02	24.65	24.45	2.06
22_1	367.83	612.83	608.05	0.79	1.95	24.54	24.35	1.99
13_7	336.34	576.46	569.62	1.20	2.85	23.55	23.27	2.93
13_{13}	332.46	565.72	558.71	1.25	3.01	23.79	23.50	3.10
22_2	363.4	605.64	596.22	1.58	3.89	24.53	24.15	4.05
Mean				1.13	2.74	24.21	23.94	2.83
Standard deviation				0.30	0.71	0.45	0.47	0.76
10.cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm%**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
22_5	363.59	604.09	599.41	0.78	1.95	24.64	24.45	1.98
22_1	367.34	612.17	607.57	0.76	1.88	24.53	24.34	1.91
13_7	337.52	577.29	565.54	2.08	4.90	23.62	23.14	5.15
13_{13}	332.33	565.19	555.47	1.75	4.17	23.81	23.40	4.36
22_2	363.31	605.38	595.89	1.59	3.92	24.53	24.15	4.08
Mean				1.39	3.36	24.23	23.90	3.48
Standard deviation				0.53	1.23	0.42	0.53	1.31
15.cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm%**	**%n**	**γ-sat (kN/m³)**	**γ-dry (kN/m³)**	**e%**
22_5	363.19	605.63	599.23	1.07	2.64	24.51	24.25	2.71
22_1	366.95	611.92	606.77	0.85	2.10	24.50	24.30	2.15
13_7	337.17	576.61	566.38	1.81	4.27	23.62	23.20	4.46
13_{13}	332.26	565.91	555.94	1.79	4.27	23.76	23.34	4.46
22_2	362.5	605.49	596.44	1.52	3.72	24.44	24.08	3.87
Mean				1.41	3.40	24.17	23.83	3.53
Standard deviation				0.39	0.88	0.39	0.47	0.94

Table J.2.2 Pink andesite values of physical properties after sodium sulphate soundness test

0.cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm%	%n	γ-sat (kN/m³)	γ-dry (kN/m³)	%e
3_5	357.03	593.34	585.96	2.31	5.66	24.63	24.08	6.00
20_1	361.07	602.34	594.28	1.36	3.34	24.49	24.16	3.46
21_2	360.03	602.37	587.38	2.55	6.19	24.38	23.78	6.59
5_1	357.84	599.11	585.12	2.39	5.80	24.36	23.79	6.16
21_1	354.4	594.3	587.38	1.18	2.88	24.30	24.02	2.97
Mean				1.96	4.77	24.43	23.97	5.01
Standard deviation				0.57	1.37	0.12	0.16	1.51
5.cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm%	%n	γ-sat (kN/m³)	γ-dry (kN/m³)	%e
3_5	358.36	594.33	581.70	2.35	5.78	24.71	24.14	6.13
20_1	361.29	602.58	593.20	1.52	3.73	24.50	24.13	3.87
21_2	361.57	603.27	585.98	2.78	6.74	24.49	23.82	7.23
5_1	359.7	600.21	582.96	2.96	7.17	24.48	23.78	7.73
21_1	356.26	595.64	582.99	2.17	5.28	24.41	23.89	5.58
Mean				2.35	5.74	24.52	23.95	6.09
Standard deviation				0.51	1.21	0.10	0.15	1.35
10.cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm%	%n	γ-sat (kN/m³)	γ-dry (kN/m³)	%e
3_5	358.61	595.02	580.31	2.53	6.22	24.69	24.08	6.64
20_1	362.21	605.38	591.67	1.97	4.82	24.42	23.95	5.06
21_2	360.28	601.44	582.22	2.77	6.73	24.47	23.81	7.21
5_1	350.54	590.11	578.07	3.88	9.20	24.16	23.26	10.13
21_1	354.66	593.94	580.11	2.56	6.20	24.35	23.74	6.61
Mean				2.74	6.63	24.42	23.77	7.10
Standard deviation				0.63	1.43	0.17	0.28	1.66
15.cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm%	%n	γ-sat (kN/m³)	γ-dry (kN/m³)	%e
3_5	359.8	595.54	579.02	2.32	5.74	24.78	24.22	6.08
20_1	361.89	602.77	588.15	1.38	3.40	24.55	24.21	3.52
21_2	361.13	601.6	580.83	2.83	6.89	24.54	23.87	7.40
5_1	341.94	577.89	575.97	4.51	10.56	24.03	22.99	11.81
21_1	356.73	595.36	580.27	2.60	6.32	24.48	23.85	6.75
Mean				2.73	6.58	24.47	23.83	7.05
Standard deviation				1.02	2.32	0.25	0.45	2.69

J.3 P-wave velocity

Table J.3.1 Grey andesite P-wave velocity values after sodium sulphate soundness test

0.cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Vp-Sat (m/s)**	**Pundit-Dry (µs)**	**Vp-Dry (m/s)**
22_5	109.00	20.30	5369.46	20.80	5240.38
22_1	109.00	20.40	5343.14	20.90	5215.31
13_7	109.71	22.80	4780.70	22.40	4866.07
13_{13}	109.70	22.30	4887.89	22.90	4759.83
22_2	109.00	20.80	5240.38	21.30	5117.37
		21.32	5124.31	21.66	5039.79
		1.03	243.07	0.84	192.68
5.cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Vp-Sat (m/s)**	**Pundit-Dry (µs)**	**Vp-Dry (m/s)**
22_5	109.00	20.40	5343.14	20.90	5215.31
22_1	109.00	20.90	5215.31	20.90	5215.31
13_7	109.71	22.80	4780.70	23.40	4658.12
13_{13}	109.70	22.20	4909.91	23.80	4579.83
22_2	109.00	20.80	5240.38	21.40	5093.46
Mean		21.42	5097.89	22.08	4952.41
Standard deviation		0.92	214.56	1.26	276.97
10.cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Vp-Sat (m/s)**	**Pundit-Dry (µs)**	**Vp-Dry (m/s)**
22_5	109.00	20.80	5240.38	21.40	5093.46
22_1	109.00	21.30	5117.37	21.90	4977.17
13_7	109.71	22.80	4780.70	22.50	4844.44
13_{13}	109.70	22.30	4887.89	22.90	4759.83
22_2	109.00	20.80	5240.38	21.30	5117.37
Mean		21.60	5053.35	22.00	4918.72
Standard deviation		0.81	187.50	0.62	138.77
15.cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (µs)**	**Vp-Sat (m/s)**	**Pundit-Dry (µs)**	**Vp-Dry (m/s)**
22_5	109.00	21.30	5117.37	21.90	4977.17
22_1	109.00	21.80	5000.00	22.30	4887.89
13_7	109.71	22.30	4887.89	22.30	4887.89
13_{13}	109.70	22.80	4780.70	22.90	4759.83
22_2	109.00	20.80	5240.38	21.50	5069.77
Mean		21.80	5005.27	22.18	4916.51
Standard deviation		0.71	162.53	0.47	103.30

Table J.3.2 Pink andesite P-wave velocity values after sodium sulphate soundness test

0.cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (μs)**	**Vp-Sat (m/s)**	**Pundit-Dry (μs)**	**Vp-Dry (m/s)**
3_5	109.01	22.90	4759.83	23.30	4678.11
20_1	109.47	22.40	4866.07	23.40	4658.12
21_2	108.89	22.90	4759.83	22.50	4844.44
5_1	108.58	22.50	4844.44	22.80	4780.70
21_1	108.56	22.40	4866.07	23.50	4638.30
Mean		22.62	4819.25	23.10	4719.94
Standard deviation		0.23	49.16	0.38	79.28
5.cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (μs)**	**Vp-Sat (m/s)**	**Pundit-Dry (μs)**	**Vp-Dry (m/s)**
3_5	109.01	23.30	4678.11	23.90	4560.67
20_1	109.47	21.90	4977.17	22.30	4887.89
21_2	108.89	22.20	4909.91	22.20	4909.91
5_1	108.58	27.40	3978.10	28.20	3865.25
21_1	108.56	22.30	4887.89	23.30	4678.11
Mean		23.42	4686.24	23.98	4580.37
Standard deviation		2.04	367.93	2.20	380.66
10.cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (μs)**	**Vp-Sat (m/s)**	**Pundit-Dry (μs)**	**Vp-Dry (m/s)**
3_5	109.01	23.40	4658.12	23.90	4560.67
20_1	109.47	21.80	5000.00	21.90	4977.17
21_2	108.89	22.80	4780.70	25.30	4308.30
5_1	108.58	28.80	3784.72	cracked	
21_1	108.56	22.80	4780.70	24.40	4467.21
Mean		23.92	4600.85	23.88	4578.34
Standard deviation		2.49	422.70	1.25	221.20
15.cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (μs)**	**Vp-Sat (m/s)**	**Pundit-Dry (μs)**	**Vp-Dry (m/s)**
3_5	109.01	23.70	4599.16	24.30	4485.60
20_1	109.47	23.80	4579.83	22.30	4887.89
21_2	108.89	23.90	4560.67	25.20	4325.40
5_1	108.58	cracked			
21_1	108.56	23.50	4638.30	24.30	4485.60
Mean		23.73	4594.49	24.03	4546.12
Standard deviation		0.15	28.72	1.06	207.88

J.4 Uniaxial compressive strength

Table J.4.1 Pink and grey andesite uniaxial compressive strength after sodium sulphate soundness test

Grey andesite							
Sample No.	**Length(mm)**	**Diameter(mm)**	**L/D**	**Area(cm²)**	**P(kN)**	**Kg/cm²**	**UCS(MPa)**
225	109	53.2	2.05	22.65	213.10	958.64	93.95
221	109	53.17	2.05	22.64	149.90	674.79	66.13
137	109.71	53.29	2.06	22.82	145.80	651.16	63.81
1313	109.7	52.34	2.10	22.33	152.50	695.92	68.20
222	109	53.22	2.05	22.66	162.70	731.59	71.70
							72.76
							10.91
Pink andesite							
Sample No.	**Length(mm)**	**Diameter(mm)**	**L/D**	**Area(cm²)**	**P(kN)**	**Kg/cm²**	**UCS(MPa)**
3_5	109.01	53.15	2.05	22.63	153.9	693.06	67.92
20_1	109.47	53.33	2.05	22.80	156.7	700.44	68.64
21_2	108.89	53.1	2.05	22.58	147.075	663.65	65.04
5_1	108.58	53.28	2.04	22.62	cracked		
21_1	108.56	53.32	2.04	22.64	155.5	699.91	68.59
							67.55
							1.48

Appendix K Magnesium Sulphate Salt Crystallization

K.1 : Mass loss

Table K.1.1 Pink and grey andesite mass loss values after magnesium sulphate soundness test

Grey andesite			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss %**
10_2	605.89	603.1	0.46
23_1	600.15	597.4	0.46
24_9	598.9	596.34	0.43
22_4	602.39	600.25	0.36
22_3	604.98	602.9	0.34
Mean			0.41
Standard deviation			0.05
Pink andesite			
Sample No.	**Dry mass before test(gr)**	**Dry mass after test(gr)**	**Mass loss %**
21_3	582.28	579.9	0.41
6_7	608.37	605.06	0.54
21_4	585.77	582.34	0.59
13_{14}	563.5	560.73	0.49
25_2	607.05	604.54	0.41
Mean			0.49
Standard deviation			0.07

K.2 Physical properties

Table K.2.1 Grey andesite values of physical properties after magnesium sulphate soundness test

0.cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm%	%n	γ-sat (kN/m^3)	γ-dry (kN/m^3)	e%
10_2	363.9	612.22	605.89	1.04	2.55	24.16	23.91	2.62
23_1	361.04	607.32	600.15	1.19	2.91	24.17	23.88	3.00
24_9	358.7	605.4	598.9	1.09	2.63	24.05	23.79	2.71
22_4	360.14	608.49	602.39	1.01	2.46	24.01	23.77	2.52
22_3	362.41	612.54	604.98	1.25	3.02	24.00	23.70	3.12
Mean				1.12	2.71	24.08	23.81	2.79
Standard deviation				0.10	0.24	0.08	0.08	0.26
5.cycle								
Sample No.	Wsub(gr)	Wsat(gr)	Wdry(gr)	Watm%	%n	γ-sat (kN/m^3)	γ-dry (kN/m^3)	e%
10_2	360.64	611.86	603.1	1.45	3.49	23.87	23.53	3.61
23_1	357.96	606.01	597.4	1.44	3.47	23.94	23.60	3.60
24_9	358.77	605.9	596.34	1.60	3.87	24.03	23.65	4.02
22_4	356.71	606.63	600.25	1.06	2.55	23.79	23.54	2.62
22_3	360.39	610.4	602.9	1.24	3.00	23.93	23.63	3.09
Mean				1.36	3.38	23.91	23.59	3.39
Standard deviation				0.20	0.54	0.09	0.06	0.54

Table K.2.2 Pink andesite values of physical properties after magnesium sulphate soundness test

0.cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m^3)**	**γ-dry (kN/m^3)**	**e%**
21_3	356.37	597.37	582.28	2.59	6.26	24.29	23.68	6.68
6_7	366.91	621.39	608.37	2.14	5.12	23.93	23.43	5.39
21_4	357.54	599.91	585.77	2.41	5.83	24.26	23.69	6.20
13_{14}	335.35	575.8	563.5	2.18	5.12	23.47	22.97	5.39
25_2	365.06	620.9	607.05	2.28	5.41	23.78	23.25	5.72
Mean				2.32	5.55	23.95	23.60	5.88
Standard deviation				0.18	0.50	0.34	0.48	0.56
5.cycle								
Sample No.	**Wsub(gr)**	**Wsat(gr)**	**Wdry(gr)**	**Watm**	**%n**	**γ-sat (kN/m^3)**	**γ-dry (kN/m^3)**	**e%**
21_3	355.64	598.15	579.9	3.15	7.53	24.17	23.43	8.14
6_7	368.46	622.85	605.06	2.94	6.99	23.99	23.31	7.52
21_4	346.08	596.38	582.34	2.41	5.61	23.35	22.80	5.94
13_{14}	330.35	575.84	560.73	2.69	6.16	22.99	22.38	6.56
25_2	360.88	619.13	604.54	2.41	5.65	23.49	22.94	5.99
Mean				2.72	6.39	23.60	22.97	6.83
Standard deviation				0.32	0.85	0.34	0.08	0.96

K.3 P-wave velocity

Table K.3.1 Grey andesite P-wave velocity values after magnesium sulphate test

0.cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (μs)**	**Vp-Sat (m/s)**	**Pundit-Dry (μs)**	**Vp-Dry (m/s)**
10_2	109.00	21.80	5000.00	21.90	4977.17
23_1	108.56	21.45	5061.07	22.90	4740.61
24_9	108.56	20.40	5321.57	20.90	5194.26
22_4	108.36	20.40	5311.76	21.00	5160.00
22_3	109.15	20.40	5350.49	21.20	5148.58
Mean		20.89	5208.98	21.58	5044.12
Standard deviation		0.61	164.94	0.75	189.40
5.cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (μs)**	**Vp-Sat (m/s)**	**Pundit-Dry (μs)**	**Vp-Dry (m/s)**
10_2	109.00	21.40	5093.46	21.90	4977.17
23_1	108.56	21.40	5072.90	22.40	4846.43
24_9	108.56	21.40	5072.90	21.90	4957.08
22_4	108.36	20.40	5311.76	20.90	5184.69
22_3	109.15	20.90	5222.49	20.90	5222.49
Mean		21.10	5154.70	21.60	5037.57
Standard deviation		0.40	107.70	0.60	160.08

Table K.3 2 Pink andesite P-wave velocity values after magnesium sulphate test

0.cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (μs)**	**Vp-Sat (m/s)**	**Pundit-Dry (μs)**	**Vp-Dry (m/s)**
21_3	109.15	24.00	4547.92	28.20	3870.57
6_7	108.58	24.80	4378.23	27.60	3934.06
21_4	108.75	24.80	4385.08	26.70	4073.03
13_{14}	109.17	21.40	5101.40	21.90	4984.93
25_2	109.58	21.40	5120.56	21.40	5120.56
Mean		23.28	4706.64	25.16	4396.63
Standard deviation		1.56	375.37	2.91	605.31
5.cycle					
Sample No.	**Length(mm)**	**Pundit-Sat (μs)**	**Vp-Sat (m/s)**	**Pundit-Dry (μs)**	**Vp-Dry (m/s)**
21_3	109.15	25.80	4230.62	30.60	3566.99
6_7	108.58	25.30	4291.70	28.70	3783.28
21_4	108.75	24.30	4475.31	30.60	3553.92
13_{14}	109.17	22.40	4873.66	22.90	4767.25
25_2	109.58	21.90	5003.65	22.30	4913.90
Mean		23.94	4574.99	27.02	4117.07
Standard deviation		1.55	347.04	3.68	668.73

K.4 Uniaxial compressive strength

Table K.4.1 Pink and grey andesite uniaxial compressive strength values after magnesium sulpate test

Grey andesite							
Sample No.	**Length(mm)**	**Diameter(mm)**	**L/D**	**Area(cm²)**	**P(kN)**	**Kg/cm²**	**UCS(MPa)**
10_2	109	53.34	2.04	22.72	185.50	831.86	81.52
23_1	108.56	53.22	2.04	22.59	175.50	791.71	77.59
24_9	108.56	52.56	2.07	22.25	176.30	807.28	79.11
22_4	108.36	53.33	2.03	22.61	174.80	787.77	77.20
22_3	109.15	53.34	2.05	22.75	173.10	775.40	75.99
Mean							78.28
Standard deviation							1.90
Pink andesite							
Sample No.	**Length(mm)**	**Diameter(mm)**	**L/D**	**Area(cm²)**	**P(kN)**	**Kg/cm²**	**UCS(MPa)**
10_2	109.15	53.15	2.05	22.65	165.10	742.73	72.79
23_1	108.58	53.18	2.04	22.57	160.30	723.68	70.92
24_9	108.75	53.12	2.05	22.57	163.30	737.30	72.26
22_4	109.17	53.15	2.05	22.65	155.50	699.44	68.54
22_3	109.58	53.12	2.06	22.71	151.40	679.40	66.58
Mean							70.22
Standard deviation							2.34