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REVIEW ON EXPLORATION OF CRUSHED VOLCANIC ROCKS AS AGGREGATE IN CONSTRUCTION

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ABSTRACT

The aggregates come from the mechanical crushing of lava rocks and pyroclastic deposits. This study offers an experimental database of the geomechanical characteristics of different volcanic rock lithotypes and the aggregates obtained from these rocks. Volcanic rock consists of various essential contents which can be positively used as a building material in construction industry. Literature review indicates that such research efforts. However, a potential research gap is found in existing literatures since there is no single research towards exploring the possibility of volcanic rocks that are available. Furthermore, correlations between the different properties of the aggregates (volumetric, geometric and mechanical properties) have been established, as well as between certain aggregate properties and the source rock. This allows an estimation of the foreseeable characteristics of the aggregates based on their origin. Laboratory investigation on volcanic rock samples has been assessed on the engineering properties. Based on the properties, it has been conducted its suitability as an aggregates in concrete. It is found that Rwanda aggregates to possess better performance with respect to workability, strength, and permeability compared. The results show that the aggregates superior resistance, partly due to their high density. These generally comply with the standard specifications although the particle shape may present an excessive flakiness index. However, the most abundant volcanic aggregates come from very porous rocks with a vesicular or scoriaceous structure, non-cubic particles, low resistance and high absorption, though they provide good drainage capacity.

Key words: Aggregates, Compressive strength, Permeability, Rwanda, Volcanic Rock, Vesicular volcanic aggregate, Scoriaceous volcanic aggregate, Pyroclastic aggregate, Pavement construction.

1. INTRODUCTION

In the construction projects, material deficiency is one of immense factor in world wide. In search of alternative material especially aggregate volcanic crushed rocks are noble option. Natural aggregates, consisting of crushed stone, gravel and sand, are the most important raw materials used in the construction industry. It is almost impossible to create structures to make people's lives easier and more comfortable without using aggregates (Akbulut and Gu¨rer, 2003; C¸ etin, 2007; Drew et al., 2002; Tepordei, 1999; Tepordei and Doud, 2001). Many industries use large quantities of natural aggregates to build and maintain the continuously expanding infrastructures in the world. Throughout the world, the two products which have the highest consumption per capita are water and aggregate (O¨ ztu¨rk et al., 2007). The use of aggregate goes back to ancient Greek and Roman times. Gravel, broken stones and sand were used in Roman roads, and concrete was made by mixing soils containing pozzolanic (silicon dioxide (SiO_2)) materials. In the 1850s, as the railway system started to develop, aggregates were commonly used as ballast materials. At the beginning of the twentieth century, with the invention of the motor vehicle, the construction of asphalt and concrete roads demanded a huge amount of aggregate (USGS, 1999). The mass destruction of the Second World War, rapid development of industry and reconstruction of destroyed cities resulted in a huge amount of aggregate use in the middle of the twentieth century. The mining industry generates 16. 5 billion tons of aggregate per year worldwide (Langer et al., 2004). In 1996, the USA generated more than twice as much aggregate as coal (USGS, 1999).

1.1 Global aggregate manufacturing and Usage

Throughout the world, aggregate manufacturing stands in the first rank, having a share of 58% among the whole mine manufacturing output. According to statistics for the year 2000, having a market share of A92 billion, aggregate manufacturing comes after petroleum, natural gas and coal, and hence stands in the fourth rank of importance. Moreover, it has a greater market share than gold, whose share is A24 billion. In Europe, the average aggregate consumption is 7.0 ton/capita whereas in Turkey it is about 4.0 ton/capita (O¨ ztu¨rk et al., 2007). The total aggregate production of the UK was 173 billion tons in 2001 (Steadman et al., 2004). Thirty per cent of this amount was for concrete production, 27% for highway construction and 25% for filling materials (Robinson and Brown, 2002). Each year in

Finland, 70 million tons of mineral aggregates are used for highway work (Mroueh et al., 2001). The 2006 annual aggregate production of Turkey was about 300 million tons, and this number has been rapidly increasing because of huge domestic, industrial 111 and highway projects that are under construction. Being very pertinent to national construction works, having a considerable employment potential, and having intense relations with other sectors, especially with the construction sector, the aggregate sector is fundamental to Turkey's economy. In Turkey, the aggregate sector is dispersed in terms of manufacturing and hence there are many manufacturing plants. It has an overwhelming market value considering its great manufacturing capacity – of 290 million tons and about US$1. 5 to US$2.0 billion. Moreover, the sector has become an important branch of mining and will become even more important with its capacity to employ approximately 20 000 people directly (O¨ ztu¨rk et al., 2007). Almost all small towns and large cities are connected via roads that are constructed and maintained with aggregates. More than 90% of asphalt pavements and 80% of concrete roads require sand, gravel or crushed stone. As aggregates have been used extensively in construction work, they form the main component of the raw materials used for highway infrastructures. Most of the unbound layers, 90–95% of the mass and 80–85% of the volume of hot-mix asphalt, and 70–80% of the mass and 60–75% volume of the concrete layers consist of aggregates (Akbulut and Gu¨rer, 2003; Akbulut et al., 2003; Asphalt Institute, 1989; Barksdale, 1991; C¸ etin, 2007; Kulogˇlu, 2007; Robinson and Brown, 2002; Umar and Agˇar, 1994; White, 1992). It is known that an average of 12 500 tonnes of aggregates is used per kilometre for double-lane carriageway construction (Akbulut and Gu¨rer, 2007). As the population of the world increases, current infrastructures will exceed their lifespans and therefore will not meet the demands imposed on them. Developing countries constantly require new runways, highways and wastewater treatment construction to meet the rapidly increasing demand. To be able to build these kinds of infrastructures, the use of large quantities of aggregates is necessary (Robinson and Brown, 2002; Werth, 1980). An increase in domestic and industrial areas limits regional aggregate resources and necessitates the discovery of new aggregate sources. Inadequate regional resources force the aggregate suppliers to transport the demanded aggregates over long distances. This, in turn, results in higher overheads and time delays, as well as wear and tear of the highway surfacing and other roads. Therefore, it is vitally important to use available aggregate resources effectively and to find new potential aggregate resources in order to meet increasing demands and protect the environment (Langer, 1993; Robinson and Brown, 2002; USGS, 1999; Vagt, 1994; Wilburn and Goonan, 1998). Aggregate samples taken from two different resources in the Afyonkarahisar–Seydiler region of Turkey were used to determine the physical properties of crushed aggregate samples via standard tests. Hot-mix asphalt tests were then carried out to determine whether the volcanic aggregate samples were suitable for use in bituminous pavement layers.

1.2 The revolutionary change of materials in infrastructure

The areas of infrastructure engineering and building materials have encountered a revolutionary change most recently by encouraging massive innovation in building materials. It is also well known that owing to better logistic services, availability of building materials in any part of the world is not a bigger issue. A closer look into the economy of the majority of the places in Rwanda shows its growing pace of improvement in construction industry in last 5 years. With availability of huge amount of volcanic rock in north-western part of Rwanda, the local industry has already started using the volcanic rocks in the form of building materials; Basic engineering characteristics are not documented for Rwanda volcanic rocks. At present, construction industry of Rwanda has already started using pyroclastics, tuffs, and ignimbrites as the main building materials. This paper discusses about investigation carried out on volcanic rock aggregates of northwest Rwanda and assesses its engineering characteristics with respect to its applicability as building materials for various types of construction of structures. This section discusses about the studies that are carried out in past for the considering natural composites e.g. volcanic rock as aggregates in building materials. Investigation show that such forms of studies started archiving since last decade. Most recently Kishore et al. have presented a study for exploring the feasibility of basalt aggregates in concrete mixtures. Using normal laboratory test and slump test analysis, the authors have calculated the compressive strength of the mixture. Zou and Zboon have investigated the case study of volcanic rocks from Jordan. The study was mainly inclined to understand the possible effect of mixing volcanic rock aggregates on cement mortar. The outcome of the study has witnessed a significant enhancement in flexural strength. Medeiros et al. have investigated the geological properties of Azoream rock with respective to alkali and silica as it adversely effects the building materials. Usage of advance computing and optimization method on volcanic rock in order to compute compressive strength was found in the work of Ozbek et al. Mathew et al.have presented a comparative analysis on the eligibility of volcanic rocks as concrete mixtures using workability, compressive strength, and bulk density. Zhu et al. have investigated the essential properties of natural rocks found in Alban hill using density, porosity, and stress mainly. Similar form of the study was also conducted by Wedekind et al. considering geological location of Mexico. Aydin et al. [10] have investigated the possible effect of volcanic rock aggregates when mixed with concrete materials to find better compressive and tensile strength. Yasar et al. and Gennaro et al.have carried out a study to investigate the effect of rocks from volcanic site in industrial utility in Turkey and Bologna (Italy) respectively. Chemical analysis was carried out to investigate the volcanic rock properties. After reviewing the above studies, it can be stated that there is some considerable research work has been carried out on the suitability of volcanic rocks to be used as coarse aggregates. All the above studies produce result with different impressions of compressive strength. Moreover, places like Rwanda was never researched before whereas in reality there lies an abundance of volcanic rocks in the north-western region of Rwanda. This fact has motivated to carry out the research in this direction of investigating the engineering behavior of volcanic rock aggregates in north-western part of Rwanda. The aggregate production and availability is also there in Jamaica as well as in Island from commercial market viewpoint.

1.3 The revolutionary change of materials in infrastructure

At the present era of technological advancement, there has been an exponential rise of urbanization leading to mushrooming of new level of demands of infrastructure. Such demands on infrastructure have become challenges for construction industry owing to location factor, climatic condition, massive capacity of occupants, etc. The conventional mechanism of building an infrastructure is no more practiced and it has started adopting new steps and technologies to meet such infrastructure demands. One of such actor that play a big role in this is, aggregates that needs to be mixed with cement or concrete. However, there different forms of aggregates that are practiced in different countries owing to geographical advantages. This leads to advantages of using local resources without tapping more resources that can be cost effective and located in another part of the world. We like to bring in notice about the volcanic rocks that are quite abundant in Rwanda. From more than a decade, volcanic rocks in Rwanda have already been used locally for the purpose of building houses. But, as volcanic rocks consist of multiple form of minerals and organic elements, it has been a matter of uncertainty of getting it standardized. Till date, it has seen there are various research work being undertaken from various countries about the feasibility of using volcanic rocks, in their country, (or ignimbrite rocks) as building materials. Hence, this manuscript is a summary of our research work where it is shown that volcanic rocks available in Rwanda can be standardized to be used as building materials. The engineering properties of Rwanda volcanic rock aggregates have been evaluated in this investigation. The suitability of Rwanda Volcanic Rock as an Aggregate in concrete has been assessed. Utility of locally available aggregates will result in cost-effective solution at Rwanda. Zouby and Zboon have used volcanic tuff of Jordan to assess its engineering characteristics with cement mortar (900g). The study outcome showed better mortar performance when mixed with volcanic tuff with respect to flexural strength. A comparative analysis was carried out by Mathew et al. on the suitability of the volcanic rocks as construction material. The outcome shows higher compressive strength (20Mpa) of concrete cubes after 28 days of curing. Similar study was also carried out by Aydin et al. The study outcome shows modulus of elasticity of approximately 17.45GPa, tensile strength of 2.53 Mpa, and compressive strength of 26.15 Mpa 28 days of curing period. Baijat have carried out a study showing the feasibility of using basalt aggregates from Jordan. The testing was carried out using shear test (1.18Mpa), flexural strength (2Mpa), permeability, and indirect tensile strength (3.6Mpa). Study of basalt rocks has been investigated by Kishore et al. in recent times in order to evaluate its applicability in construction industry in the form of aggregates. Ozbek et al. have presented an optimization technique to compute the compressive strength of volcanic rock. The outcome of the study was assessed using slump test and compressive strength. Hossain have carried out a study evaluating the engineering characteristics of pumice element found in volcanic rock to be used in concrete. The study shows that the characteristics of volcanic pumice when mixed with various forms of aggregates, it generates better workability, surface absorption, strength, and permeability performance. Azoream rock is another type of volcanic rock and it was investigated by Medeiros et al. The study uses with silica and alkali for assessing its possible effect on building materials in construction industry. Apart from volcanic rock, natural rocks were also investigated by Zhu et al. for exploring the possible mixing in concrete as an aggregate. Zhu et al have investigated about the rocks present in surroundings of Alban Hill and have discussed the outcomes with respect to porosity, density, and stress. The samples were found to possess nearly 35 Mpa of compressive strength. Study in similar direction was also carried out by Wedekind et al.considering natural rocks of Mexico. The study shows to achieve compressive strength of samples to 19.3Mpa, elastic modulus of 5Mpa. Similar trend of research work was observed in the work carried out by Gennaro et al. and Yasar et al. who have investigated the effect of rocks from volcanic site in industrial utility in Turkey and Italy respectively. In the wake of surveying the above studies, it can be expressed that there is some extensive investigation work being done on exploring the appropriateness of volcanic rocks when utilized as an aggregates in building materials. Notwithstanding, all the above studies produces diverse consequence of compressive quality and fluctuated laboratory outcomes. Rwanda is abundant in volcanic rocks especially in north-western area of Rwanda. Hence, the experimental investigation has been made on the volcanic rocks of Rwanda regarding its suitability as an aggregate.

1.4.1 Importance of Aggregates in construction industry

Aggregates are fundamental in the construction industry. They constitute one of the most consumed products in the world and one of the four most important raw materials in world mining. In volcanic regions, and especially on island territories, there are numerous environmental, technical and economic limitations and constraints regarding the exploitation of these aggregates. In this sense, it is fundamental to know the properties of all the natural aggregates in order to consider possible applications for different construction uses. The endogenous origin of volcanic territories determines a great variability and heterogeneity of existing trod volcanic aggregate lithotype are volcanic age materials and their properties even within the same quarry or natural deposit. The spatial distribution of the different rocks is usually unpredictably irregular and discontinuous, either due to the wide diversity of possible lithologies (basalts, basanites, trachytes, phonolites, rhyolites, etc.), the different rock structure (massive, vesiculated, isotropic, anisotropic), the type of alteration (hydrothermal, diagenetic, weathering, thermal contact) or the type of eruption that produced the rocks quarried for aggregates (effusive, explosive). This accumulation of constraints explains the lack of scientific-technical literature regarding the implementation of volcanic aggregates. The main objective of this study is to promote the diversification of usable volcanic material for construction implementation in these regions where resources and territory are limited as well as protected environmentally. Bearing this in mind, an exhaustive geo mechanical characterization of the main lithotypes is offered for possible use in the construction of road or airport pavements, used as unbound granular material, or as an aggregate for asphalt mixture or for cement concrete. However, for this last application additional testing would be necessary: chemical stability, alkali-silica reactivity, long-term durability of unstable minerals. From these properties, characterized by the European test standard (EN), correlations between the different properties of volcanic aggregates and between these and the source rock are presented in order to infer expected properties as long as the origin is known. In this way, the following characteristics were determined: particle density (EN 1097-6), water absorption (EN 1097-6), flakiness index (EN 933-3), percentage of crushed and broken surfaces (EN 933-5), sand equivalent (EN 933-8), sand friability (UNE 83- 115-89), resistance to wear (EN 1097-1) and resistance to fragmentation (EN 1097-2); as well as the following properties of the original rock: bulk density (EN 1936) and uniaxial compressive strength (EN 1926). Finally, a simplified classification of volcanic aggregates for engineering applications is confirmed which will simplify the complex geological classifications and thus allow technicians and operators take decisions regarding the possible construction uses of a certain type of volcanic aggregate. There are studies that support the use of certain volcanic aggregates in road engineering. Some studies even analyse the use of certain marginal volcanic aggregates (ashes, scoriae, tuffs, basaltic lapilli) in cement concrete and in asphalt mixtures based on the hydraulic capacity, profitability and low mp life he c h d classification was originally recorded b ear (E broken surf 10 s N 1097-6), g he or zed by the d bet kali Europ crete. silica rea How ements, us er, f acter limited a ti c material reg environmental impact. However, the performance of the final product will always depend on the individual properties of each one of the component materials and the proportion in which they are used up to now, characterization studies of volcanic materials have focused on determining the properties of certain aggregates after analysing the rock characteristics. Generally speaking, when it comes to analysing the quality of an aggregate, a resistance characterization is carried out using tests such as Los Angeles (LA) and Micro-Deval (MDE). Other studies have sought a way to estimate the values of LA and MDE coefficients by indirect tests that are quicker and more affordable. Certain studies explored the way to deduce the LA coefficient from the results obtained with the Schmidt hammer, Point Load Test (PLT) 85 and the porosity. To this effect, this study analysed samples of igneous, metamorphic and sedimentary rocks with different LA coefficients (10-76%). The results showed a certain correlation between the LA coefficient and the Is of the Point Load Test (R2 = 0.72) and with the Ir results obtained by the Schmidt hammer (R2 = 0.62). Furthermore, the correlations clearly improved separating the samples according to their porosity (n1%). Further studies, that analysed different non volcanic lithotypes according to petrology, porosity and density, provided LA values from electric resistivity, density and porosity, accomplishing a good correlation between electric resistivity and the LA coefficient. In Ref. the LA coefficient, the uniaxial compressive strength (UCS) and the bulk density (ρb) of various volcanic lithotypes from the Canary Islands (Spain) were correlated and it was concluded that it is possible to estimate the UCS from the LA and ρb; these last properties can be obtained in an easier, quicker and more affordable manner.

1.4.2 Concrete role in construction industry

Concrete is indeed the most important material in the construction industry. It comprises water, cement, fine aggregate, and coarse aggregate. The latter component typically consists of crushed rock that forms up to 60–80% of the concrete volume and 70–85% of the concrete mass. The presence of coarse aggregate is paramount for the strength, thermal, and elastic properties of concrete, as well as concrete dimensional and volume stability. For the last two decades, the number of ready-mix concrete batch plants worldwide has increased exponentially. In Egypt, more than 50 million cubic meters of concrete were produced in 2021; dolomitic rocks represent around 75–85% of concrete aggregates, produced mostly from the quarries of Gabal Ataqa (located between the Suez Governorate and the Red Sea Governorate). However, recently, ongoing developments within Gabal Ataqa to transform it into a tourist attraction have ended up closing many existing quarries. The most popular of such aggregate-producing sites are namely Ben Laden, El-Daly, New-Gravel, Ready Rocks, El-Khawaja and Lafarge. In turn, exploring and discovering aggregate substitutes has become a necessity. Several authors have studied alternatives to dolomitic aggregates: e.g., Ismail and Ghabrial studied the use of acidic igneous rocks (granites) as aggregate in concrete production; ref. studied the use of basic Dokhan volcanics as aggregate in concrete mixes; and ref. presented a study exploring the feasibility of basalt aggregates in concrete mixtures. The latter also used normal laboratory tests and slump test analysis along with calculating the compressive strength of the mixture. In ref, the effect of incorporating volcanic tuff into cement mortar was investigated. The outcome demonstrated a significant enhancement in flexural strength.Investigated the geological properties of Azorean lava rocks as regarded their alkali and silica content; adverse effects on the properties of building materials were observed. The application of advanced computing and optimization methods onto volcanic rocks to compute compressive strength was evident. In ref, a comparative analysis was conducted on the eligibility of volcanic rocks within concrete mixtures, in terms of workability, compressive strength, and bulk density. The researchers of investigated the potential effect of volcanic rock aggregates when mixed with concrete materials to ameliorate their compressive and tensile strength(s). Refs. carried out a study to investigate the effect of rocks from volcanic sites on the industrial utilities of Turkey and Bologna (Italy). The effort at hand infers upon the geology, petrography, and geochemistry of Dokhan volcanics in Egypt and the possibility of their utilization as aggregates in concrete mixes. For this purpose, six field occurrences of Dokhan volcanics were investigated: Makhar Seal Wadi Abu Zoghot, Wadi El-Ghafiryia, Wadi Al-Radah–Luman, Wadi Al-Ushsh, Wadi Umm Sidrah, and Gabal Ghuwayrib (along El-Sokhna–Hurghada Road) aggregate-producing sites are namely Ben Laden, El-Daly, New-Gravel, ReadyRocks, El-Khawaja and Lafarge. In turn, exploring and discovering aggregate substitutes has become a necessity. Several authors have studied alternatives to dolomitic aggregates: e.g., Ismail and Ghabrial studied the use of acidic igneous rocks (granites) as aggregate in concrete production; ref. studied the use of basic Dokhan volcanics as aggregate in concrete mixes; and ref. presented a study exploring the feasibility of basalt aggregates in concrete mixtures. 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1.5 The volcanic rock powder in Mars

Mars is one of the planets in the Solar system and the fourth planet from the Sun. Due to the fact that the rotation period of Mars and the tilt of the rotational axis relative to the ecliptic plane are similar to those of earth, its days and seasons are much similar to those of Earth (David Alderton, 2021; Ziyuan and Fugen, 2012; ESA, 2010). These characteristics of Mars and its unique topography and landforms have aroused strong interest in Mars exploration and the possibility of future Martian immigration. So far, Mars is the planet most understood by humans other than the Earth. More than 30 probes had reached Mars and conducted detailed surveys on Mars to obtain a large amount of valuable data and images (Ziyuan and Fugen, 2021 Tongji 2012). In the future, the Mars exploration missions of various countries worldwide will continue to advance, aiming to further explore the external environmental conditions and internal structure of Mars, and lay the foundation for further realization of human mission to Mars. Mars exploration started in 1960 when the Soviet launched the first probe Mars 1960A, which failed but marked as the beginning of human exploration of the Red Planet. In 2011, Ouyang et al. (Ziyuan and Fugen, 2011) summarized the Mars missions from the 1960s to 1990s. During that period, Mars exploration mainly took place in the United States (8 launches, 6 success) and the Soviet (15 launches, 1 success). In 1971, the Mariner 9, part of the National Aeronautics and Space Administration (NASA) Mariner Program, successfully entered orbit around Mars for the first time, took high-resolution photographs of satellites of Mars for the first time, and worked in Mars orbit for nearly a year (NASA, 2011). At the end of the 20th century, the U.S. ‘‘Mars Pathfinder” was one of the most successful Mars exploration missions in history, this mission carried in-depth analysis on the Martian atmosphere, climate, and geology and the composition of its rocks and soil (Cook and Spear, 1998; Thomas et al., 2011). In the 21th century, with the progress and innovation of space science and technology, Mars exploration has received more attention.

1.5.1 Geological study in Mars

Many countries have made or are planning their programs towards Mars, among which are the U.S., Russia, European Space Agency (ESA), China, Japan and India (Wikipedia Exploration of Mars, 2021; Wikipedia SpaceX, 2021; National Geographic, 2009). In the early 2000s, the U.S. and ESA carried out their missions to Mars respectively. April 7, 2001, the U.S. launched the Odyssey, which is still in orbit, using spectrometers and a thermal imager to detect evidence of potential water and ice, as well as studying the geology and radiation on Mars (Wilson et al., 2018). In 2002, Odyssey firstly discovered that there may be abundant ice in the near-surface layers of Mars. In 2004, ESA also announced that its ‘‘Mars Express” probe had discovered the presence of frozen water in the south pole of Mars (Encrenaz and Sotin, 2005). Till Sept 2020, a discovery is reported based on MARSIS radar studies, of a three more subglacial lakes on Mars (Lauro et al., 2021). In 2004, the US President George W. Bush. proposed human exploration to Mars as the ultimate goal of future space exploration. In the U.S., currently there are multiple active plans and programs to put humans on Mars within the next ten to thirty years: In 2002, Elon Musk established the SpaceX, aiming at reducing the cost of space transportation and developing a rapid reusable launch system (Wikipedia Exploration of Mars, 2021; Wikipedia SpaceX, 2021). On 30 May 2020, SpaceX successfully launched two NASA astronauts into orbit on a Crew Dragon spacecraft, making it the first private company to send astronauts to the International Space Station (ISS). However, because of the current COVID-19 pandemic, proper quarantine procedures were taken to prevent the astronauts from bringing COVID-19 aboard the ISS (Masunaga, 2020). In 2015, NASA issued its official plan for human exploration and colonization of Mars, which was named as ‘‘Journey to Mars”. The plan operates through three distinct phases including Earth Reliant, Proving Ground and Earth Independent. In 2016, China launched its first Mars exploration mission, and successfully delivered the Tianwen-1 directly into the Earth Mars transfer orbit in 2020. The Tianwen-1 entered Martian orbit successfully in February 2021 and will study the magnetosphere and ionosphere of Mars along with other climate characteristics (Zou et al., 2021). Till February 20th 2021, Mars is host to eleven functioning spacecraft: eight in orbit and three on the surface, as shown in this paper, and the landing sites of various Mars rovers are presented. It is widely proposed that Mars will be the next destination for human inhabitation. However, building up a habitat requires collective work from multiple disciplinaries, of which engineering is an indispensable part. Similar to urban construction, the technical issues including raw material development, space construction technology and intelligent maintenance must be addressed before human inhabitation. The objective of this paper is to review a series of current Mars exploration results and focus on the research about the in-situ resources which can be further utilized for infrastructure construction on Mars, feasible infrastructure construction technologies are proposed as well. This paper provides an overview of Mars in-situ engineering resources, possible construction methods and prospects which can be a valuable reference for future infrastructure construction on Mars.

1.6 Need / Objectives / Scope for the Study

The construction industry is complex in its nature especially infrastructure domain. The lagging of construction materials big task in globally. The volcanic rocks may the alternative for material deficiency mainly for aggregate. This kind of Construction issues brings to do the research in volcanic rocks as an aggregate in infrastructure. The aim of this research is to analyse the resource constraint factors material deficiency in with in construction projects. Only construction projects in India are considered for this study. The volcanic rocks usage in construction site are identified from the literature survey and experts opinions. The aim of this research is divided into the following objectives: To study the geological and engineering properties of volcanic rocks. To identify the replacement factors of volcanic rocks as an aggregate in construction projects. To identify the most significant factors of volcanic rocks. To evaluate the engineering properties at various stages. To develop an appropriate methodology for material testing and cast testing. To interpretate the results on crushed volcanic rocks and its performance in construction projects. This Research / Study illustrates the evaluation of engineering properties on concrete, the role of crushed volcanic rocks as an aggregate in infrastructure construction projects. Prior to embarking on any study, it is necessary to define the volcanic rocks scope and to fnd the feasibly of when the volcanic rocks used in infrastructure as an aggregate in concrete. The aim is to provide a clear explicit shared understanding of the process that will be implemented. The tasks required to accomplish this aim are the production of a scope document and a plan document.

2. LITERATURE REVIEW

. 2.2 Resources utilized for infrastructure construction on Mars

(Jiawen Liu a , Hui Li a,, Lijun Sun a , Zhongyin Guo a , John Harvey b , Qirong Tang c , Haizhu Lu d , Ming Jia e aKey , China, 2022) It is widely proposed that Mars will be the next destination for human to expand colonization. However, building up a habitat requires collective work from multiple disciplinaries of which engineering is an indispensable part. Similar to infrastructure construction on the earth, the technical issues of raw material, space construction technologies has to be addressed before human inhabitation. Based on the history of Mars exploration missions and a series of current Mars exploration results, this paper introduces the environment conditions on Mars, reviews the research of the in-situ resources which can be further utilized for infrastructure construction on Mars and proposes feasible infrastructure construction technologies. This paper provides an overview of in-situ construction material resources, possible construction methods and requirements for materials in extreme environment, which can be a valuable reference for future Mars exploration and possible infrastructure construction on the Mars.

2.2.1 Types of in-situ resources for infrastructure construction

The discovery of water and possible life on Mars, the most Earth-like planet in the solar system, has stimulated the interest in further exploration of Mars. It's not clear whether Mars will be the next place for human to inhabit, while some assumptions and hypothesis may be necessary before the journey to Mars. 1. In-situ resources including Martian soil, basalt and Martian concrete are among the most feasible future construction materials on Mars. However, these materials should endure low pressure, low temperature, large temperature difference and high space radiation, including Galactic Cosmic Rays and UV. As for Martian concrete, its molding process and maintenance methods under harsh environment conditions need in-depth study. 2. Nuclear energy and solar energy are the main objects of Mars energy exploration. In the future, energy sources that can be further developed as in-situ resources include nuclear energy, solar energy (thermal power generation) and wind energy. Energy combination and storage technologies are needed to realize the stable and continuous energy support. 3. Intelligent construction on Mars is inevitable since the damage of the Martian environment to human bodies remains a mystery. 3D printing can be applied to produce construction materials from in-situ resources on Mars. Robots with swarm robotics and automated management systems are needed to carry out the intelligent construction process, and human on Earth should be able to make real-time controls. 4. On the basis of finding the appropriate in-situ resources for construction and in-depth understanding of the Martian environmental conditions, the development of materials that fulfills the requirement of resiliency, durability and economy.

2.3 Importance of Aggregates in the construction industry

(Hu¨ seyin Akbulut, Cahit Gu¨rer, Sedat Cetin Turkey, 2011) Aggregates are one of the most important raw materials used in the construction industry. It is almost impossible to create a structure without using aggregates. The worldwide mining industry generates 16.5 billion tons of aggregates annually. An increase in domestic and industrial areas limits the regional aggregate resources, and highlights the need to find new sources of aggregate. Difficulties in using regional resources force aggregate suppliers to transport aggregate over long distances, resulting in additional time and expense, as well as rapid deterioration of highway infrastructures. Thus, it is vitally important to use available aggregate resources effectively and to find new environmentally friendly potential aggregate resources to meet the increasing demand. Therefore, aggregate samples taken from two different aggregate resources in the Afyonkarahisar–Seydiler region of Turkey were examined. In order to determine the physical properties of crushed aggregate samples, standard tests were carried out to evaluate whether the volcanic aggregate samples were suitable to use in bituminous pavement layers. In the present study, four different aggregate samples were used: volcanic aggregate 1 (V1), volcanic aggregate 2 (V2), limestone 1 (L1) and limestone 2 (L2). The V1 and V2 samples were volcanic rocks taken from the Tekerek and Kepez areas, respectively. These samples had trachy-andesite composition based on their geochemical and petrographical observations. The L1 and L2 samples were provided from quarries in the Karacaoglan and Cobanlar areas, respectively. Both L1 and L2 samples have been currently used in hot-mix asphalt pavements. The test results indicate that the sample V1 made of volcanic aggregates displayed adequate performance on a wearing course with heavy traffic. Sample V2 did not display enough deformation resistance as a bituminous mix; however, it could be used for surface courses because of its good friction properties. Highway constructions worldwide demand a huge amount of aggregates that are resistant to heavy and increasing traffic loads. Thus it is important to find new aggregate resources that meet the standard properties demanded for road construction and so the properties of possible aggregate resources within a region need to be evaluated. The present study was performed in order to determine the feasibility of the use in hot-mix asphalt of aggregate originating from volcanic aggregate resources in the Afyonkarahisar–Seydiler region of Turkey. This is vitally important for the highway construction industry which demands durability and resistance to long-term traffic friction on the road surface. After applying standard aggregate tests on the prepared aggregate samples, hot-mix asphalt tests were also carried out on bituminous hot-mix samples prepared with these aggregates. In the second phase of testing, the samples generated in the laboratory (V1 and V2) and those used for making the asphalt mix were then used to evaluate the mix in heavy traffic conditions using the Marshall design method. The parameters for Marshall stability, flow and density values were plotted on graphs. These data indicate that samples V1, V2, L1 and L2 had optimum bitumen ratios of 5.9, 5.3, 5. 0 and 5.2%, respectively. All these values were within the economical values specified in Turkish Highway Specifications (Republic of Turkey, 2006). According to the Marshall stability value, sample V1 had much greater stability than sample V2. Of the limestone samples, sample L1 had greater stability than L2. Comparing all mixes, the stability of the mixes was L1 .V1 . L2 .V2. In general, although a high stability value is a requirement for heavy traffic, load-bearing capacity, high stability and low flow values represent a fragile hot-mix asphalt material. The volcanic aggregate sample V1 had a more porous surface in comparison with the limestone aggregates, which was reflected in its lower flow value. Although the stability and flow values of V1, L1 and L2 were found to be within the specification limits, the stability of sample V2 was low. According to the Marshall stability and flow value results, V1, L1 and L2 may show elastic behaviour under heavy traffic conditions. In terms of void contents, samples V1, L1 and L2 met the specification limits. Sample V2 had a higher void content than that required by the specifications. The density of the mixes was L2 . L1 .V1 . V2. It can be concluded that V1, L1 and L2 can resist adverse weather conditions and bear heavy traffic loads. The rutting test results show that the samples produced from the V1 aggregate had a greater tendency toward rut deformation in comparison with the samples produced from the L1 and L2 aggregate resources. Samples L1 and L2 had adequate rutting deformation resistance. The sample produced from V1 had a more porous aggregate surface and greater texture owing to a higher bitumen ratio, compared to the other samples, leading to a higher deformation resistance. Samples made with coarse volcanic aggregates, when mixed with fine limestone aggregate, may help to decrease the bitumen ratio and increase the mechanical performance of the hot-mix asphalt. The test results indicate that, although sample V1 was made of volcanic aggregates, it displayed adequate performance on a wearing course with heavy traffic. Sample V2 did not display adequate deformation resistance as a bituminous mix; however, it can be used for surface courses because of its good friction properties. The volcanic aggregate resources found in several parts of Turkey, especially in Afyonkarahisar, have superior physical and mechanical properties. Therefore, they could be used in wearing courses of hot-mix asphalt pavements. This not only prevents damage caused by heavy traffic load, but also contributes to decreasing maintenance costs

2.4 Suitability of Volcanic Rock as an Aggregate

Mutabaruka Jean de Dieu, Prof. M. R. Pranesh Volcanic rock consists of various essential contents which can be positively used as a building material in construction industry. Literature review indicates that such research efforts from Jordan, Mexico, Italy, Turkey etc. are also made. However, a potential research gap is found in existing literatures since there is no single research towards exploring the possibility of volcanic rocks that are available in Rwanda. Laboratory investigation on volcanic rock samples of Rwanda has been assessed on the engineering properties. Based on the properties, it has been conducted its suitability as an aggregates in concrete. It is found that Rwanda aggregates to possess better performance with respect to workability, strength, and permeability compared with that from Jordan, Mexico and Turkey. At present, construction industry in various parts of the world is adopting all new measures that can incorporate increased productivity with quality and reduced cost of raw materials. In this direction, building materials plays a significant role in any construction industry where cement should be mixed with certain aggregates in order to increase its robustness, durability, and strength. In this direction, it is explored that there is availability of volcanic rocks in Rwanda, which has not received much attention from research community. The volcanic rocks available in Rwanda are already being used for building houses in the local regions and yet to get better exposure in global construction industry. This factor has motivated us to pursue to the investigation of volcanic rocks as an aggregates in concretes. The proposed study defines its problem as – To explore the feasibility of using volcanic rocks of Rwanda by studying its engineering characteristics and assessing its suitability as aggregates in concrete. The proposed system uses standard method of workability analysis, strength analysis, and permeability analysis for the sample to find that volcanic rocks in Rwanda can be suitably used in building materials. It was been shown that concrete elaborated with crushed volcanic rocks to possess mechanical properties with excellent behavior: the design value for compressive strength, 25Mpa, was obtained with a margin of at least 18.4%.

2.5 Geomechanical Characterization of Volcanic Aggregates

Cándida García-González a , Jorge Yepes b, Miguel A. Franesqui a,* 5 a Grupo de Fabricación Integral y Avanzada In volcanic terrains and in particular island regions, the aggregates come from the mechanical crushing of lava rocks and pyroclastic deposits. This study offers an experimental database of the geomechanical characteristics of different volcanic rock lithotypes and the aggregates obtained from these rocks. For this purpose, aggregate samples and rock samples of different common volcanic lithotypes (including basalts, trachybasalts, trachytes, phonolites, ignimbrites and pyroclasts) were tested. These represent the majority of stone materials found in volcanic islands. Furthermore, correlations between the different properties of the aggregates (volumetric, geometric and mechanical properties) have been established, as well as between certain aggregate properties and the source rock. This allows an estimation of the foreseeable characteristics of the aggregates based on their origin. The results show that the aggregates from massive lithotypes provide superior resistance, partly due to their high density. These generally comply with the standard specifications although the particle shape may present an excessive flakiness index. However, the most abundant volcanic aggregates come from very porous rocks with a vesicular or scoriaceous structure, non-cubic particles, low resistance and high absorption, though they provide good drainage capacity. The high rties en ce stone f the agg s, tr materia am achyt olcan mples and 6 This ic rock li slan stud ons, t (M.A. Fr as de Gr pain. ran C ersidad de Las statistic dispersion of the geomechanical properties is due to the different viscosity of the magmas, degrees of explosiveness of the volcanic eruption and random spatial distribution. Even the abundant vesicular and scoriaceous volcanic aggregates, generally considered as marginal materials, may offer adequate quality and properties for certain construction applications. In this sense, the use of these aggregates might contribute to the development of infrastructures in these regions and thus a sustainable utilization of this natural material. From the analysis of the results of this experimental study the following conclusions may be drawn: Volcanic aggregates for engineering purposes may be classified for practical reasons in three extensive groups according to density, porosity (absorption) and resistance: massive, vesicular and pyroclastic. This simple classification allows users to take immediate decisions regarding possible construction applications depending on the volcanic aggregate available; and simplifying the much more complex geological classifications. anic a accor y aggregat NS of the resu e ro LA) of t) Ma 80 (M 421 The high statistical dispersion of the results shows the heterogeneity of the volcanic aggregates and in particular the pyroclasts. This variability is associated with both the geology and the production process of the aggregate. Among the geological factors the following are noteworthy: the geochemistry of the magma, the explosiveness of the volcanic eruptions and the random and discontinuous character of the spatial distribution of lava flows. The resistance of the volcanic aggregates is directly related to the mineralogy, porosity and grade of alteration of the source rock, and possibly with the elasticity modulus of the material. Furthermore, as the porosity increases so does the variability of the mechanical behaviour. This is particularly significant in the 429 case of the pyroclasts. There is a relation between the intrinsic and mechanical properties of the original volcanic rock and the resulting aggregate. It is possible to estimate the aggregate LA coefficient from the rock UCS, as well as the aggregate particle density if the rock bulk density is known. The massive volcanic aggregates offer excellent resistance properties with high durability for road and airport paving, due to the high density and low porosity. However, certain lithotypes may present a flakiness index above the recommended limits established in the standard specifications. The vesicular and scoriaceous aggregates present high porosity associated with the high speed decompression and cooling of the lava flows. This determines a high absorption, rounded particle geometry with reduced percentage of crushed and broken surfaces, and susceptibility to weathering damage. For this reason, it would be advisable to limit their use to materials for base and subbase layers. The pyroclastic aggregates are only recommended for use as permeable subbases and subgrades, permeable low-weight fillings or in non-structural light concrete, due to the low density, high porosity and limited resistance to fragmentation although they offer excellent drainage capacity. The use of local volcanic aggregates is a logistic and economic necessity especially in volcanic regions that 444 are environmentally protected or in countries with limited technical and economic resources. Even the abundant vesicular and scoriaceous aggregates, generally considered marginal, can provide adequate quality yrocla eight ould b astic ag ntag be advisab olin e of aceo ng of the la us aggreg estab xcellent ow po i esista wn. ef ies of th fficient f he or ticularly oro . Furth ty and g rmor and performance for certain construction applications and therefore could contribute to the development of these areas and provide sustainable natural materials. For sustainable utilization of volcanic aggregates for cement concrete, additional chemical testing (stability, long-term durability) would be necessary.

2.6 Engineering Characteristics of Volcanic Rock Aggregates

Mutabaruka Jean De Dieu Applicability of the volcanic rock aggregates in the construction industry are still in the stage of exploration of finding best building materials. Usage of volcanic rock as an aggregate could prove one global identity of Rwanda in Infrastructure engineering as the place has abundance of rich volcanic rocks especially in the north-western part. This paper investigates the engineering behavior of volcanic rock aggregates with respect to performance standards e.g. compressive strength, point load test, and permeability analysis. Tested on International Standards of ASTM D4630-96(2008) and UNIEN 1926:2006, the outcome of the study is compared with one of the recent work on similar direction to find volcanic rock aggregates from Rwanda could be suitably use in construction industry. With the rise of population, there is a dynamic growth in urbanization that leads to a bit of unbalanced or trade-off in present requirement of infrastructure and services provided by construction industry. Although, bigger giants of construction industry are still in exploration of best building materials that doesn’t only provide safety but also comes with cost effectiveness. Hence, this paper presents a discussion where volcanic rocks are highlighted to have possible contribution in building materials. The existing literatures have been reviewed. Volcanic rocks have higher compressive strength; however, much is not explored for Rwanda, which has some of rich availability of volcanic rocks. It is found that samples of Rwanda have very high compressive strength and better permeability, which is one of the essential characteristics of building materials. Also compared our study outcomes with one recently executed research using Ahlat stone, which is also a type of volcanic rocks. The outcome shows proposed system to excel better performance compared to existing system. It is suggested that Volcanic Rock aggregates of Rwanda possess higher potentials. Hence it is a suitable material as an aggregate.

2.7 Potential Source for Construction Aggregate

Hatem El-Desoky 1 , Nabil Abd El-Hafez 1 , Ahmed Khalil 2 , Ahmed Arafat 3,*, Mahmoud Galal Hasan 4 and Tarik Youssef 5,* The present paper focuses on the geology, petrography, and geochemistry of the wellknown Dokhan volcanics encountered in the northern part of the Eastern Desert of Egypt. The basalts, andesites, rhyolites, and agglomerates exposed at the Makhar Seal (flood plain) as well as Wadi Abu Zoghot, Wadi El-Ghafiryia, Wadi Al-Radah Luman, Wadi Al-Ushsh, Wadi Umm Sidrah, and Gabal Ghuwayrib are herein examined as sources of coarse aggregate in concrete mixes. A representative total of 28 samples—collected from different Dokhan volcanics—was studied in terms of field geology, petrography, and geochemistry wherein a variety of experiments related to construction material validation apply. The petrographic examination revealed that the studied Dokhan volcanics consist of basic, intermediate, and acidic volcanic igneous rocks. These rocks are represented through basalts, andesites, imperial porphyry, dacites, rhyodacites, rhyolites, and their pyroclastics. Furthermore, the applied geochemical analysis indicated that the studied Dokhan volcanics are alkaline to sub-alkaline, calc-alkaline and classified as basalts, basaltic andesites, andesites, trachyandesites, trachydacites, trachytes, and rhyolites, indicating an initial potential as aggregate for concrete mixes. Finally, the results obtained from incorporating Dokhan volcanics as aggregates in concrete mixes demonstrated a significant improvement in regard to the properties of the comprising concrete mixes. Herein, a higher compressive strength was witnessed after 28 days for Dokhan volcanic concrete, when compared to concrete comprising dolomite aggregate, amounting to an average increase that exceeded 36%.

2.8 Exploration of Natural Aggregates for a Sustainable Construction Industry

Mario Maya 1,2,* , José Luis Parra 1 and Benjamín Calvo 1 The sources of aggregates for construction materials in the area surrounding Medellín, Western Colombia, are experiencing a significant decrease due to the depletion of their resources and reserves and the policies of land use in territorial planning. The objective of this study is to identify and assess the potential sources of aggregates for the construction industry in Medellín. A lithological characterization is made in the field and laboratory tests are performed to determine the physical and chemical behaviour of the rocks in the lithostratigraphic units. The study allowed us to define the properties and quality of rocks and to map sand and gravel in unconsolidated deposits in the weathering zone of granitic rocks and in stratified rocks. The results allowed us to define the preliminary physical and chemical quality of these rocks and assess their potential as raw material for use in the construction industry. This work constitutes a tool for civil and mining authorities in making decisions on land-use policies and the proper use of resources in the face of the growth and demand requirements of these materials. 1. Introduction Sands and gravels are a staple in infrastructure creation, urbanization, water treatment and land reclamation. For this reason, the consumption and production of sand and gravel has implications for social and environmental management in infrastructure projects, sustainable city planning, energy planning and biodiversity conservation. Additionally, sand and gravel resources are the second largest resource extracted and traded by volume after water; however, it is one of the least regulated activities in many regions. Thus, there is an increasing demand for information on geological materials and their geotechnical and characteristics and on other natural resources, because these materials affect the occupation of space in urbanized areas. The current extraction of aggregates for the construction industry shows a projection of demand in the world that rises from 24 million to 55 million tons per year in the period 2011–2060. This situation could lead to an impact on ecosystems, with irreversible damage, in addition to increasing concern regarding the global scarcity of sand and the consequent appearance of social conflicts. Achieving spatial data and systematic mapping of resources and consumer relationships would show how each supply flow is linked to specific environmental and social outcomes. This knowledge would allow researchers, companies and governments to understand, organize and facilitate the production and consumption chain to optimize resources and meet the strategic development needs of communities. Recognizing the unprecedented demand for sands for the construction industry requires systematic mapping of resources, at both the local and regional levels. The extraction of large volumes of sand and rocks for construction causes adverse impacts on the environment and affects economic and social development. Therefore, the joint and weighted management of geological, environmental and socio-economic parameters is a priority for informed decision making. The Aburrá Valley Metropolitan Area, in its study "Integral management of quarries and mining exploitations of materials for construction in the Aburrá Valley" indicated that, even at that time, most of the exploitations of construction materials in Medellín and its surroundings lacked mining planning and design. The urban sector around Medellín is an area of 1200 km2 made up of nine municipal administrative entities and has a population of 3,700,000 inhabitants. The extractive activities of sands and gravels in the area are carried out under parameters of unsustainability that leave serious damages of difficult and expensive repair, both physically, economically and socially, which is related to small and artisanal mining companies that carry out low-tech processes. The Energy Mining Planning Unit, an agency of the Colombian state, conducted research on the market for construction materials in several cities in Colombia, including Medellín and its metropolitan area. The demand for

construction materials in Medellín totaled 8.77 million tons for 2013. Since 2008, the average variation in the number of tons of materials shipped to Medellín has been 2% per year, with a consumption of 2.5 tons per person. In 2025, Medellín will demand 11.9 million tons of aggregate products, which will mean a demand of 3.1 tons/inhabitant. The objective of this work is the mapping and determination of the preliminary physical and chemical quality of the lithostratigraphic units in the surrounding area of Medellín to define their potential for use as aggregates for concrete in the construction industry and as a tool for civil and mining authorities in making decisions on land-use policies and the proper use of resources. The study area is located in north-western Colombia, in sectors of the Central and Western Andes Cordillera. The region is composed of igneous, metamorphic and sedimentary rocks related by a fault system, mainly north–south. In addition, there is an intense weathering, typical of a tropical area, with soil formation up to 20 m deep.

The present work of aggregate exploration in the surrounding area of Medellín, Colombia, has allowed us to obtain a cartography of potential units of sand and gravels for the construction industry, with a preliminary regional characterization of their physical and chemical parameters. Materials located in unconsolidated deposits, such as alluvial and terraces, show good results in the physical and chemical tests. In local exploration campaigns, the silica–alkali reactivity test must be performed, especially when the lithology contains quartz material. Stratified rocks, such as sandstones and conglomerates, can be used as raw material for aggregates, with subsequent processing in the plant. These are quartz rocks that did not present positive silica–alkali reactivity in a preliminary way, although this situation must be taken into account in the local definition of resources to understand their behaviour. The sandy massifs are a source of abundant sand due to their well-developed weathering profiles. Specific gravity meets the requirements, but sieve material 200 (ASTM) and flat, friable particles must be controlled. Igneous rock units present a variety of materials with good, acceptable and poor conditions to be used as aggregates. In general, intrusive rocks and volcanic rocks show good physical results (LA Test) and good specific gravity, but rocks that have a significant quartz component may be reactive to silica–alkali. Metamorphic units have a high potential for aggregates when they have a massive or gneiss structure. These rocks have poor potential when they are schist due to the high presence of micas and deformed quartz. It has been possible to classify the potential of lithostratigraphic units to obtain natural aggregates according to the basic tests of granulometry, apparent weight, absorption, Los Angeles Test and flat and friable particles. In addition, the angularity and shape of the grains in the alluvial and stratified materials were determined. The initial chemical behaviour has been achieved with the analysis of silica reactivity—alkali, presence of sulphates (SO4) and the presence of organic impurities (Fe2O3) Mapping potential rocks for natural aggregates allows the construction industry to focus the search for raw materials from sand and gravels. This cartography is a basic tool for civil authorities to make decisions regarding territorial planning.

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