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FATIGUE CHARACTERISATION OF MARTIAN CONCRETE: A REVIEW

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Graphical abstract

Abstract

Spacecraft have been dispatched to Mars as part of human missions aimed at exploring new frontiers, driven by the observed similarities between the red planet and Earth. This endeavour has facilitated the development of construction materials suitable for human settlements on Mars. To determine the optimal properties for constructing habitable infrastructure for humans on Mars, research efforts have led to the discovery of Martian concrete, composed of sulphur and Martian simulants that had been produced without water, which is in scarce supply on Mars. By utilising egolith available near the construction site, structures can be built efficiently and rapidly, supporting the establishment of sustainable human habitats on Mars. Several studies have been conducted to address the challenges associated with identifying the ideal proportions of Martian concrete. Given the extreme and harsh conditions on Mars, there is a growing interest in understanding how the properties of Martian concrete can mitigate and alleviate fatigue resulting from the planet's daily conditions, such as temperature variations and dusty storms, which impose cyclic loading on structures. Therefore, it is crucial to investigate the fatigue characteristics of Martian concrete. By evaluating the fatigue properties of Martian concrete, considering the selected appropriate mix design ratios, this study aims to contribute to understanding the impact of Martian conditions on construction practices. Ultimately, the findings of this study can assist future researchers in comprehending the effects of the Martian environment on the planet's construction process.

Keywords: Martian concrete, fatigue, mix design ratio, Mars.

1.0 INTRODUCTION

Martian exploration has drawn tremendous attention because it is possible to live on this planet. Organisations such as SpaceX and NASA have proposed a human mission to Mars, the first exploration effort, in which no human ever set foot on the planet. Before exploration, landers and rovers successfully settled on the surface and delivered information about the conditions on the ground [1]. Reasons for the exploration of Mars include curiosity, the potential for humans to produce additional in-depth data-based analysis than pilotless rovers, an economic interest in its resources, and therefore the risk that the settlement of alternative planets might decrease the probability of human extinction [2]. To perform in any respect, the colony would want the essential utilities to support human civilisation, which might be designed to handle the harsh Martian environment. Difficulties and hazards include radiation exposure throughout a visit to Mars and its surface, toxicant soil, low gravity, isolation that accompanies Mars' distance from Earth, water scarcity, and cold temperatures. Since the twentieth century, there have been many planned human missions to Mars by public houses and government agencies that are cherishing NASA, ESA, Roscosmos, ISRO, the CNSA, and personal corporations such as SpaceX, Lockheed Martin, and Boeing. However, the surface of Mars is not hospitable to humans or other well-known life forms because of radiation [3], significantly reduced air pressure, and oxygen [4]. (As a result, humans explored components of Earth that match some conditions on Mars to make up a habitable condition for life forms to survive in the Martian environment with only) 0.16% oxygen [4]. As a result, humans explored components of Earth that matched some conditions on Mars to make up a habitable condition for life forms to survive on Mars.

1.1 Problem Background

The idea of human settlement on Mars involves establishing a self-sustaining human community on planet Mars. This concept has gained significant attention and interest in recent years owing to advancements in space exploration technology and its potential for long-term space missions. NASA and private companies such as SpaceX have been actively exploring the possibility of sending humans to Mars and establishing a permanent presence there [5], [6]. The main objectives of human settlement on Mars include scientific research, exploration, resource utilisation, and the potential for future colonisation. One of the key references in this context is NASA's "Journey to Mars" initiative. It outlines a three-phase plan for human exploration of Mars, starting with Earth-reliant missions, followed by the "Proving Ground" phase near the Moon to test deep-space capabilities, eventually leading to Earth-independent missions on Mars [7]. SpaceX, founded by Elon Musk, has been at the forefront of Mars colonisation plans. Musk envisions sending large spacecraft, such as Starship, to transport humans and cargo to Mars [8]. SpaceX's long-term goal was to establish a self-sustaining colony on the planet. Musk emphasised the importance of developing technologies to make Mars a liveable environment, including creating a propellant plant on Mars to enable return missions to Earth [9].

The future exploration of Mars is a rapidly evolving field of research and interest. As part of broader efforts to establish a human presence on the Red Planet, NASA is preparing to launch the Mars 2020 Rover, and SpaceX intends to begin human-crewed missions in 2024 [10]. Several critical factors must be considered in terms of the challenges associated with human settlement on Mars. The journey to Mars is long and requires overcoming the technological and physiological hurdles. The development of advanced propulsion systems, life support systems, and spacecraft capable of long-duration space travel is crucial. Additionally, the health risks posed by extended exposure to space radiation and microgravity must be addressed. Creating sustainable habitats on Mars is another challenge. The thin atmosphere, extreme temperatures, lack of liquid water, and high radiation levels render Mars inhospitable for humans. To overcome these challenges, concepts such as constructing pressurised habitats, utilising underground caves for radiation shielding, and developing technologies for resource extraction and utilisation (such as in-situ resource utilisation) are being explored. Several robotic missions to Mars, such as the Mars rovers Curiosity and Perseverance, have provided valuable data on the planet's geology, climate, and potential future resources. These missions have contributed to our understanding of Mars and helped plan future human missions.

To survive in the Martian environment with a lack of resources, several essential utilities are needed to ensure that human colonisation on Mars works as planned and that Mars can be habitable for humans. A crucial requirement of a Martian settlement is the construction of safe and durable structures from locally produced materials. Concrete has consistently been suggested as an essential structural material, and many formulations and methods have been proposed. The successful application of concrete on the the Red Planet will require a comparative review of the various options and an analysis of their suitability to the unique conditions of the Martian environment. As a result, [11] developed a method for preparing Martian concrete using materials that are available in generous supply on Mars and without using water, which is a resource that will be limited and precious on the planet by replacing it with sulphur, a resource that is limitless on Mars. This establishment helps reduce the dependency on Earth for construction materials, as regolith is abundantly available on Mars. Utilising local resources minimises the need for costly and resource-intensive transportation of construction materials from Earth. Compression testing showed that Martian concrete reached a compressive strength of 50 MPa or more, owing to the strong chemical bonds that sulphur forms with the Martian soil during curing. The authors explained that compared to standard concrete used in buildings on Earth, with a compressive strength of approximately 20 MPa. This improved compressive strength will be necessary on Mars because the planet's atmospheric pressure and temperature range are wide compared to Earth's more hospitable conditions.

Gratefully, this investigation had driven many researchers to experiment with Martian concrete to create a mixture design that would face any circumstances and conditions on the planet which can be tailored to different applications and design requirements by adjusting the composition and mix ratios. The utilisation of regolith, which is considered an inert material on Mars, Martian concrete has a minimal environmental effect and promotes sustainable construction practices by reducing the reliance on Earth's resources and minimising waste generation. It is important to note that while significant interest exists in human settlements on Mars, this remains a complex and long-term goal. Many technological, logistical, and ethical considerations must be addressed before humans can establish a sustainable presence. Bearing in mind the risks and with a continuous stride to overcome them, Mars colonisation, a distant dream now, could be accomplished while realising the major enhancements and discoveries that would happen in all fields of science and technology in the future [12]. Nevertheless, the idea of human settlement on Mars continues to inspire scientists, engineers, and space enthusiasts, driving innovation and research in space exploration.

1.2 Problem Statement

Although many researchers started experimenting with Martian concrete, the researches that had been conducted was not comprehensive owing to the parameters that had been studied. There are too many options for inspecting on the composition of Martian soil to the sulphur by other researchers without considering the local conditions such as extreme temperature and harsh environment on Mars itself—temperatures on Mars average about -63 °C. However, temperatures range from around -140 °C in the winter at the poles to 21°C over the lower latitudes in the summer. The possibility of Martian concrete collapsing due to higher drop temperature ranges is high despite the higher compressive strength at normal temperatures on Earth.

Future investigations into the fatigue characterisation of Martian concrete are also needed because of the harsh conditions of the Mars itself. Mars has clouds and wind just like Earth; sometimes, the wind blows red dust into a dust storm [13]. Tiny dust storms can look like tornados, and large storms can be seen on Earth, sometimes covering the entire planet. These windstorms are common on the red planet, lifting rust-coloured dust well into the atmosphere and encircling the entire globe. The microcracks of the structure on Mars will change, expand, connect, and stabilise at a certain level or crack final destruction in the end because of the massive windstorm which could be defined as the structurebeing subjected to cyclic loading. Cyclic loading can lead to structural fatigue

Structures on Mars are subject to significant mechanical stresses owing to harsh environmental conditions, such as extreme temperature variations, low atmospheric pressure, and the possibility of earthquakes. An analysis of the material's response to repeated loading and unloading is needed in addition to providing insights into the behaviour of materials under cyclic stress. It is important to determine their fatigue life and strength, as well as their ability to withstand long-term stress [14]. Thermal expansion and contraction, atmospheric pressure changes, and earthquake activity can induce cyclical stresses on Martian habitats and infrastructure [15]. The fatigue characterisation of concrete ensures the long-term structural integrity of Martian construction by assessing the resistance of the material to cyclic loads. Researchers and engineers can assess the durability of a material by performing fatigue tests on it over extended periods. It is possible to identify and estimate the service life of Martian concrete samples by repeatedly loading and unloading them under conditions representative of the anticipated operational conditions.

Thus, the needs of further study on the fatigue characterisation of Martian concrete involving extreme temperatures are needed to ensure that the potential of using Martian concrete for construction on Mars is the best option that had been suggested while facing circumstances such as extreme temperatures and a massive and harsh environment on Mars.

2.0 LITERATURE REVIEW

2.1 Idea of Construction on Mars

For most of its history, concrete has played a crucial role in the development of the planet. Romans and Egyptians used it to construct their empires, and after the secret of making concrete was forgotten, it was rediscovered in the 1300s. The current yearly production of more than 2 billion tons of concrete is predicted to more than triple by 2050 [16]. Concrete, a common building material on Earth, comprises several types of rocks and minerals (called aggregates) that are mixed and held together by cement. The terms "cement" and "concrete" are sometimes used interchangeably, although, in chemical terms, water is the "cement" that binds "concrete" together. When concrete is mixed with water, a series of chemical reactions occurs, causing it to harden into a durable solid matrix after drying. When humans start exploring other planets for habitual purposes , such as Mars, concrete will be needed to construct buildings and infrastructure. Even though Mars fits in the characterisation that is needed for the habitual process, constructing concrete for construction purposes on it would be a massive problem owing to the non-existence of water, which is an essential part of making concrete, although the aggregate of a part of concrete is simple to search out on Mars.

However, Mars has a lot of sulphur, perhaps the maximum amount as 17% of the whole planet. That is why [11] suppose that sulphur is the key to the in-depth construction boom of the Red Planet. As a result, they found the answer by heatingsulphur to 240 °C until it is liquefied and using it instead [11]. However, sulphate concrete has been attempted before. In the 1970s, material scientists investigated the possibility of using sulphate concrete to construct lunar outposts. The issue with this idea is that sulphur does not turn into a liquid even under the most extreme conditions of a vacuum [15]. Sulphur concrete cannot be driven on planets without a related nuclear atmosphere since it instantly transforms from a solid to a gas.

As Mars has an associated atmosphere that is not a vacuum-like moon, they discovered that it is sufficient to form sulphur concrete. By using simulated Martian soil as a replacement for aggregates to form sulphur concrete, [17] mentioned that the scientists tested different mixes of it with sulphur. They determined the optimum concrete formula for a durable Martian abode. Using simulated Martian soil consisting of semiconducting material dioxide, aluminium oxide, iron oxide, and atomic titanium dioxide that had been mixed into a combination of 50/50 with liquefied sulphur, they created blocks of quasi-Martian concrete.

Wan et. al. also declared that the mix style will manufacture a robust, two-and-a-half times as strong compared to the most typical concrete used on Earth [11]. This is a result of the sulphur bonding with chemicals in the minerals found in Martian soil, whereas on Earth, only sulphur is the glue for gravel [17]. Furthermore, because gravity on Mars is a common fraction of that on Earth, the strength is effectively tripled.

According to [18], Martian concrete has an additional benefit over its earthly counterpart. Concrete manufacturing is the third - largest source of greenhouse gas emissions worldwide, mostly because of the amount of concrete used. The use of concrete does not help slow manufacturing; however, as we constantly tear down concrete buildings, it takes a lot of time and energy to rebuild from scratch. Martian concrete, on the other hand, can be reheated until the sulphate melts and the whole block becomes flexible again, making it essentially indefinitely recyclable without suffering the same wear and tear as earth concrete.

The compositions of Martian soil simulants, which are used to create Martian concrete, has been the focus of several studies. Martian soil simulants have been found to have a wide range of chemical and mineralogical compositions, including silicates, iron oxide, and aluminium oxide, which can affect the mechanical properties of the resulting concrete [19]. These methods have revealed that the mechanical properties of Martian concrete are affected by several factors, including the composition of the Martian soil simulants, curing conditions, and environmental conditions on Mars, such as temperature fluctuations and radiation exposure.

2.2 Martian Constituent

The ballistic capsule's journey to Mars is fraught with difficulty. It has an atmosphere that is too thin to be of any help for anchoring, but is also just thick enough to cause issues. When mudslides roll in worldwide, they may obscure the light for weeks at a time, and the temperature can swing drastically between day and night [20]. Mars is covered by a thin layer of sand and dust formed by the weathering of iron-rich igneous rocks resembling basalt. This substance, which has the catchy name "Regolith", is typically a type of dust, that may be coarse, fine, or implausible. This dust is always a threat to equipment on the surface of Mars because it is blown by the wind and remains suspended in the atmosphere. The intake filters and movable parts of solar panels are often blocked by debris and locked in place. Without proper precautions, future human-crewed trips to Mars might put human health in danger from the regolith [21].

The surroundings of other worlds are used to ensure that the technology being delivered there is almost as effective as possible on Earth. The durability of spacecraft components, including landers, rovers, solar panels, and mechanical arms, should be evaluated in harsh Martian environments. Since no Martian regolith has ever made it to Earth, researchers needed a technique to test how well their designs would hold up in a Martian environment by simulating the Red Planet's surface on Earth. Martian concrete is a building material designed specifically for use on the surface of Mars. Concrete is a popular building material on Earth, but its behaviour on Mars may differ because of the harsh environmental conditions and low atmospheric pressure on the planet. Martian concrete is typically made by mixing Martian soil with water and a binding agent such as iron oxide. The resulting material is strong and durable, making it well suited for use in building structures on Mars. The development of Martian concrete is crucial for establishing a sustainable human presence Buildings constructed from Martian concrete would provide a protective environment for astronauts and equipment, allowing them to operate safely on the Martian surface [22]. To ensure the safety and reliability of structures built from Martian concrete, it is important to thoroughly characterise its mechanical behaviour and performance, including its fatigue behaviour. This can be achieved through various experimental methods such as fatigue testing and numerical simulations. The results of the fatigue characterisation of Martian concrete can be used to improve its design and performance, thereby ensuring the safety and sustainability of human settlements on Mars.

2.3 Martian Soil Simulants

It has been suggested by [23] that the Martian soil simulants are mineralogically, chemically, and/or geotechnically similar to Martian regolith and could be used for a variety of purposes, including but not limited to scientific research, education, mission development, and testing and developing unaltered in-situ resource utilisation (ISRU) technologies. To be effective, the fidelity of a simulant must be tailored to the specific needs of its intended use. For testing rover wheels, for example, a stimulant that closely matches the geotechnical properties of materials on the Martian surface is needed.

ISRU is particularly interested in Martian soil simulants because of the prevalence of soil (here defined as loose particles) on the Martian surface and the relative ease with which it may be mined compared with rock. The United States Space Agency and the European Space Agency created four Martian soil simulants: JSC Mars-1, MMS, Salten Skov I, and ES-X. These can be used for a wide range of tasks, such as calibrating spectroscopes, testing instruments for rovers and landers, and determining how the physical properties of Martian soil will affect the mechanical properties [24].

Martian soil simulants are used for various purposes, including testing equipment and instruments that will be used on Mars, developing and testing Martian construction materials, and studying the behaviour of plants and other organisms in a Martian environment. Some of the most commonly used Martian soil simulants are MMS- 1, Mars-500, and JSC Mars-1. MMS-1 simulant was developed by the Mars Society and is based on the data from the Mars Odyssey orbiter. MMS-1 is a mixture of iron-rich Martian soils and is commonly used in studies on Martian agriculture and plant growth. Mars-500 simulant was developed by the European Space Agency, and is based on data from the Mars Express and Mars Reconnaissance Orbiter missions. Mars-500 is a mixture of basaltic soils and oxides and is used (to test) the durability and performance of spacecraft components and equipment [25]. JSC Mars-1 simulant was developed by NASA's Johnson Space Centre, and is based on data from the Viking and Mars Pathfinder missions. JSC Mars-1 is a volcanic ash that closely resembles the composition of Martian soil and is commonly used in studies of the habitability and life of Mars.

Martian soil simulants are designed to mimic the physical and chemical properties of Martian soil. They are used in various applications, including testing equipment and instruments used on Mars, developing and testing Martian construction materials, and studying the behaviour of plants and other organisms in a Martian environment. Martian soil simulants are typically made by mixing various minerals, such as basalt and iron oxide, as shown in Figure 1, to match the composition of the Martian soil as closely as possible. They can also be tailored to mimic the specific properties of Martian soil, such as its grain-size distribution, porosity, and mineral composition.

Martian soil simulants are essential for preparing for future Martian missions and for studying the potential for life and human settlement on the planet. They allow scientists and engineers to test equipment and technologies in a Mars-like environment and to study the behaviour of plants, animals, and other organisms under these conditions. In addition to their practical applications, Martian soil simulants also provide valuable information about the composition and properties of Martian soil, which can help to better understand the planet's geology and habitability. Overall, Martian soil simulants play a crucial role in preparing for future Martian missions and in advancing our understanding of the planet [10].

NASA's Jet Propulsion Laboratory (JPL) developed Mojave Mars Simulant 1 (MMS-1) in 2007 to aid the success of the Mars Phoenix mission. [26] conducted research and concluded that it is made of Saddleback Basalt from the same locations as the JPL Phoenix mission. [26] conducted research and concluded that it is made of Saddleback Basalt from the same locations as the JPL. The majority of MMS-1 can be found in its natural, unaltered state as complete rocks that are then further broken down into smaller pieces or separated into granular basalt. The absence of substantial weathering, along with the coarse angular particles produced by the crushing process, renders these materials impervious to hygroscopic reactivity. Researchers may utilise the rock or blend different chemical components of crushed rock to simulate the properties of Martian regolith and permafrost, depending on the tests they want to do.

Figure 1 Image of MMS Simulants [26]

2.4 Martian Concrete Failure

Martian concrete failure refers to the point at which a concrete structure or component used on Mars can no longer perform its intended function, owing to a loss of strength, stiffness, or stability. In the context of fatigue, failure can occur in Martian concrete structures when they are subjected to repeated loading cycles, and the size of the cracks or fractures grows to a point where the concrete can no longer sustain the applied loads. The likelihood of failure in Martian concrete structures depends on several factors, including the composition of Martian soil simulants used in the concrete mix design, curing conditions, and environmental conditions on Mars. For example, exposure to harsh Martian environments, including temperature fluctuations, high levels of radiation, and dust storms, can affect the strength and durability of concrete [22].

To study Martian concrete failure, a variety of experimental techniques can be used, including fatigue testing machines, which apply repeated loads to a sample of concrete until failure, and numerical simulations, which use computer models to predict the fatigue behaviour of Martian concrete. The results of these studies can be used to improve the design and performance of Martian concrete structures and components and ensure their reliability and longevity on the Red Planet.

2.5 Basic Concepts of Fatigue

Fatigue failure occurs when the load required during a single stress application that causes failure is much higher than that required for the application of fluctuating stresses. It is estimated that fatigue contributes to approximately 90% of all mechanical operational shortcomings [27]. Fatigue can affect any moving component. Examples of fatigue failures include ships at sea, cars on highways, nuclear reactors, jet engines, aeroplane fuselages and wings, and turbines on land.

Fatigue is a phenomenon in which a material gradually loses strength and eventually fails under repeated loading or cyclic stress. The strength of a material is reduced by the initiation and growth of cracks over time, (which leads) to a decrease in its ability to withstand stress. Fatigue can occur in all types of materials including metals, polymers, and composites. Fatigue is a common cause of failure in engineering structures and components such as bridges, aircraft, and vehicles. It is particularly important to consider these applications because they are subjected to repeated loads such as traffic, wind, and vibration.

To prevent fatigue failure, designers must understand the fatigue behaviour of the materials they use and design structures to withstand the repeated loads experienced by them. This may involve the use of materials with high fatigue resistance, improving the surface finish of the components to reduce the initiation and growth of cracks, and using stress-relief techniques to reduce stress concentrations. Fatigue testing is a common method for evaluating the fatigue behaviour of materials, and numerical simulations can also be used to predict the fatigue behaviour. The results of fatigue testing and simulations were used to improve the design and performance of engineering structures and components, thereby ensuring their reliability and safety over time.

In the early 19th century, fatigue was declared a problem when researchers in Europe observed bridge and railway components cracking under repeated stress. An increasing number of component failures have been recorded as the use of metals expanded as the century progressed owing to the increased use of machinery that has been loaded under repeated stress [28]. Today, structural fatigue has become even more important due to the increasing use of high-strength materials and the desire for higher performance of these materials.

2.6 General Condition on Mars

The daily conditions on Mars vary depending on the location, season, and time of the day. However, a general feature of Martian weather is the temperature on Mars is much lower than that on Earth. The average temperature on Mars is approximately − 63°C, but can range from -125°C near the poles in winter to 20°C at midday near the equator [29], [30]. The diurnal temperature range could be as large as 58°C. The atmosphere on Mars is very thin and low-pressure. The atmosphere on Mars is mainly composed of carbon dioxide (95.32%), nitrogen (2.7%), and argon (1.6%) [31]. The atmospheric pressure at the surface is only 6.35 mbar, which is over 100 times less than that of Earth [32].

The wind on Mars can be strong and gusty, particularly during dust storms. The wind speed on Mars can reach 60 m/s (216 km/h) near the surface [15]. Dust storms can occur frequently and can sometimes cover the entire planet for several months. These storms can reduce solar power generation and erode the surface of structures [33]. In addition, precipitation on Mars is very rare, and mostly occurs as frost or snow. Water exists on Mars; however, the atmosphere is too thin for it to last long on the surface in a liquid state [34]. Instead, water on Mars is found below the surface of the polar regions as water ice, and also as seasonal briny water flowing down hillsides and crater walls. Sometimes, water ice clouds can form in the atmosphere and produce frost or snowfall [30].

This daily condition of Mars can affect its construction in many ways. Some of the challenges faced by engineers and builders are that the low gravity on Mars can cause problems for the stability and strength of structures [32], as well as the mixing and curing of materials. For example, Martian concrete may require different proportions of ingredients and additives to prevent segregation and cracking. Radiation on Mars can also damage the materials and electronics used for construction and pose health risks for human workers [15]. For example, polymers and metals can degrade under radiation exposure, thereby reducing their mechanical and electrical properties. Therefore, radiation shielding and protection are essential for Martian construction.

Other studies have concluded that the power on Mars can be limited and unreliable, especially during dust storms, which can block sunlight and reduce solar power generation. Therefore, alternative and backup power sources, such as nuclear reactors and batteries, are required for construction on Mars. As stated in [31], the atmosphere on Mars can affect the performance and durability of materials and structures as well as the operation of machines and tools. For example, a thin atmosphere and low pressure can affect the hydration and curing of concrete, increase the risk of outgassing and evaporation of volatile substances, and render pneumatic or hydraulic systems less efficient.

A study by [35] stated that transportation on Mars can be difficult and costly, especially for heavy or bulky materials and equipment. Therefore, in situ resource utilisation (ISRU) , which involves the use of local materials and energy sources to produce construction materials and components, is a key strategy for construction on Mars. For example, Martian soil, basalt, and Martian concrete are possible in-situ materials for construction on Mars.

2.7 Importance of Fatigue Studies on Mars

Considering the conditions on Mars, some of the environmental conditions on Mars can lead to fatigue of the construction, such as low temperatures and large temperature variations. The average temperature on Mars is approximately − -63°C, but can range from -125°C near the poles in winter to 20°C at midday near the equator. This can cause thermal stress and cracking in materials, especially those that are brittle or have a low thermal conductivity. The thin atmosphere and low pressure also contributed to the development of fatigue in the construction that had been built on Mars. The atmosphere on Mars is more than 100 times thinner than that on Earth and is mainly composed of carbon dioxide. The atmospheric pressure at the surface is only 6.35 mbar, which means that water cannot exist in the liquid form on the surface. This can affect the hydration and curing of some materials, such as concrete, and increase the risk of outgassing and evaporation of volatile substances [36]. Mars has a weak magnetic field and no global ozone layer, which means that it is exposed to more solar and cosmic radiation than Earth. High radiation and dust storms can degrade the mechanical and electrical properties of some materials such as polymers and metals [37]. Moreover, Mars experiences frequent and intense dust storms that cover the entire planet for months [38]. This can reduce solar power generation, erode the surfaces of structures, and clog the filters and vents of the machines.

To address this issue, an analysis to study the behaviour of any materials under the pressure of a changing load needs to be performed. Two loads are normally applied to a material: a load of a specific mass (i.e. zero) and an alternating load. It ran through and measured these loads until the material failed. The term fatigue life (fatigue degradation) can be used to represent the failure of these materials under fatigue conditions. Most engineering materials, such as ceramics, aggregates, and composites, are rone to fatigue damage , as they are not limited to metals. Regardless of the low loading, cyclic loading generally cause specimen failure. This may be achieved by repeated loading of compression-compression, tension-tension, tension-compression, or some other type of cyclic loading combination. However, for some materials, the Wohler (S-N) curve flattens out, and it is suggested that for these materials, a load limit or the so-called fatigue limit can be specified, below which infinite service life can be expected. To collect and compile the S-N curve data, tests must be performed on force-controlled specimens to determine the number of failure cycles for each specimen. Using this curve, the cyclic load capacity of the materials was analysed, and their durability was evaluated.

By referring to some studies on the development of the proportions in creating Martian concrete, it can be used to develop the fatigue properties for human settlement on Mars, as it is a novel material that uses sulphur as a binder and Martian soil as an aggregate. While studies have shown that it has the advantages of high strength, fast setting, acid and salt resistance, no water requirement, and recyclability [39], no recent studies have considered the relationship between Martian concrete and Martian environments. A lack of comprehensive understanding of its fatigue characteristics exists because of the limited data available on how Martian concrete performs under such cyclic loading. Martian concrete is composed of regolith and potential additives, which can vary in properties and composition depending on their specific location on Mars [40]. Understanding how different compositions and mixtures of Martian concrete affect its fatigue behaviour is a challenge that needs to be addressed. Developing appropriate test methodologies to evaluate the fatigue properties of Martian concrete can be another challenge, as the test conditions and parameters need to be carefully designed to simulate the actual stress cycles experienced by structures on Mars.

Thus, the needs of this study are important, as fatigue can affect the safety, performance, quality, and durability of construction materials and structures. Fatigue affects the performance and durability of construction materials and structures such as concrete, steel, asphalt, and wood. This can cause progressive damage and failure of a material or structure over time. As the study on Martian concrete has developed, the understanding of its fatigue characterisation should be addressed, as it is crucial for designing resilient structures, optimising construction techniques, and ensuring the long-term durability and safety of human habitats and infrastructure on Mars. It also helps in evaluating the fatigue resistance and life cycle of construction materials that have been used under different loading and environmental conditions and optimises the design and maintenance methods to enhance their reliability and sustainability.

3.0 CONCLUSION

The study of fatigue development on Mars construction is a vital and challenging topic that can have significant implications for the feasibility and sustainability of human settlement on the red planet. Fatigue can affect the material aspects of construction on Mars, such as the quality and durability of materials and structures and the design and maintenance methods. Therefore, it is important to understand the causes and effects of fatigue on the construction of Mars and to develop innovative and adaptive solutions to prevent and reduce fatigue, such as selecting suitable materials and technologies. By doing so, we can ensure the reliability and sustainability of materials and structures, and the success and efficiency of construction on Mars. Recognising the critical role that fatigue behaviour plays in the construction and long-term durability of human habitats on Mars, researchers and scientists are motivated to delve deeper into this aspect. This has led to an increase in new studies that specifically target fatigue testing and analysis, aiming to uncover the material's fatigue strength, fatigue life, and failure mechanisms. The importance of fatigue characterization characterisation has driven the development of improved testing methodologies and protocols tailored to the unique challenges posed by Martian conditions. Researchers are exploring innovative approaches to simulate the cyclic stresses experienced by Martian structures, thereby enabling more accurate assessments of the fatigue properties of Martian concrete. Its importance shapes the trajectory of future investigations, leading to a more comprehensive understanding of the fatigue behaviour of Martian concrete and contributing to the development of sustainable and resilient infrastructure for human habitation on Mars.

By attributing previous studies, it will provide some benefits to research on the future exploration of Mars. The suitable mix design of the selected Martian soil to the sulphur for Martian concrete that had been identified through several studies can be used to develop a study on the fatigue characterisation of Martian concrete. Using the same concept of determining of a suitable mix design of concrete that can sustain certain loadings on Earth, this concept can be applied to determine a suitable mix design for the construction on Mars which helps to minimise the inaccuracy in evolving this study. The best proportion of the mix design is used to deduce and differentiate how the proportion of the materials contributes to the strength. From the above results, the fatigue characterisation of Martian concrete can be acquired through a fatigue test. As the conditions on Mars are different from those on Earth, this investigation is needed to determine whether the construction that is soon to be built on Mars can sustain massive windstorms and extreme temperatures on the planet. It will also help and give ideas to researchers to develop a structural design that can withstand any circumstances that would be faced during construction on Mars.

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