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Properties of Sustainable Concrete Containing Red Mud: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. Author KSK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. The Authors YA and TG managed the analyses of the study. Authors YA and TG also managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Concrete is an essential construction material and major component of concrete is cement. There is a huge amount of carbon dioxide emission into the atmosphere during manufacturing process of cement which has negative impact on the environment. Thus it become necessary to discover a substitute material for cement in concrete. Rapid industrialization generates a significant quantity of waste material which are causing negative effect on environment. These wastes can be a replacement for traditional material which are used in concrete like cement or fine aggregate. Red mud is waste material which generated from bauxite ore at the time of production of aluminium by the Bayer process. In this review paper, the effort is made to present the properties of concrete with red mud after studying several research papers. This paper discusses the properties of red mud concrete such as workability, compressive strength, split tensile strength, flexural strength, water absorption and modulus of elasticity. This paper shows the feasibility of partial substitution of cement in concrete by red mud. The study shows that incorporating red mud resulted increase in strengths of concrete such as compressive, split tensile and flexural strength. The water absorption of concrete decrease as increase in red mud content, it can be established that there is a possibility for using red mud in concrete as a binder ingredient for sustainable construction.

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Keywords: Red mud; compressive strength; split tensile strength; flexural strength; water absorption.

1. INTRODUCTION

Cement is one of the essential material in structural constructions since it is used to made mortar or concrete at various levels of construction. Carbon dioxide is emitted during cement production. Based on some research it has been showed that 1 tons of clinker produces around 1 tons of carbon dioxide. This causes severe environmental damages, which can be avoided by using alternative materials to partly substitute cement in concrete [1].

Red mud is the primary waste produced by the Bayer's process in the production of aluminium and alumina, is classified as a high alkaline slurry due to its high pH. CaO, SiO_2, Fe_2O_3, Al_2O_3, TiO_2 and Na_2O are the six key oxides found in red mud, along with some small amounts of a variety of minor elements since some of the oxides stated above are also found in cement, therefore red mud is classified to as a cementatious material [2]. Cheap and readily available construction materials must be prioritised, so it is crucial to identify and use appropriate waste products to substitute with traditional materials. Cement demand is currently far beyond supply, and it is increasing growing [3-6].

In 2008, the world's bauxite production was 205 million tons, Australia, China, Brazil, Guinea, India and Jamaica supplying the majority of it. The study of red mud for different uses, such as an unconventional building material, has resulted from the need for an inexpensive and environmentally feasible alternative [7]. Red mud's high alkalinity, which is originally a source of environmental problem, has proven to be the primary benefit of utilizing it as a rebar corrosion inhibitor in reinforced concrete without compromising its passivity [8-10].

1.1 Impact of Red Mud on Environment

During monsoon season, the traditional practise of dumping red mud in ponds has a number of negative environmental impacts. The waste can be carried to surface water courses by run-off, and as a result of leaching, the waste can pollute ground water and deplete soil fertility [11-13]. When huge quantities of red mud are dumped in the future, storage issue may become more prevalent. Ground water may polluted-when the red mud got mix with water, Alkali seepage in to underground water supplies including wells and aquifer may get polluted. Disposal of red mud in land changes the property of soil and result in lesser fertility [13-17].

Several researchers have found that red mud shows promising behaviour when blended with cement in concrete and has immense potential used in certain applications.

Sethy et al. [18] examined the strength properties of concrete carrying up to 20% red mud in place of cement. They reported from the experiment work that till 10% has no noticeable effect on concrete properties after 10% significant drop in compressive strength.

Metilda et al. [19] determined the practicability of using red mud to partial substitute of cement in concrete and investigated its compressing strength and splitting tensile strength. They discovered that red mud can effectively substitute 15% of cement. After 15% both compressive strength and tensile strength start decreasing.

An experiment was carried out to in which red mud was used to partially substitute cement in concrete at various percentage (0%, 5%, 10%, 15%, 20%) along with 5% hydrated lime and examined for compressive strength, tensile strength and workability. 17% improvement in strength by using of red mud was reported by Sapna and Aravindhraj [20].

Sawant et al. [21] assessed the effects of red mud in concrete. They reported from the experiment work that reduction in setting time at 5% and 10% cement replacement with red mud. Strength also reduced with increase in red mud quantity in concrete.

A study was conducted on properties of red mud concrete in which cement was substituted up to 40% with red mud and evaluated its compressive strength and splitting tensile strength. Rathod et al. [11] discovered that compressive strength and splitting tensile strength was increased till 25% replacement of cement with red mud. Wang et al. [22] studied the performances of Bayer red mud and sintering red mud. X-Ray Diffraction (XRD) and Scanning electron microscope (SEM) analysis were used to determine their compositions, mechanical properties and microstructure characterization. Bayer red mud was found to have a high reuse value and moreover utilized as a masonry mortar mixing material.

Most of the studies suggested to use up to 20% cement replacement with red mud. Also found in various studies that an increase in the concrete's compressive strength as well as split tensile strength was up to 10% cement substitution. Nikbin et al. [23] reported that red mud can be utilized till 25% replacement of cement. They conduct tests for compressive strength, splitting tensile strength, modulus of elasticity (MOE) and flexural strength. They discovered that raising the amount of red mud in concrete reduces compressive strength, spitting tensile strength, MOE and flexural strength [23-27].

2. WORKABILITY

2.1 Slump

The workability of concrete, which is determined using a slump test, compaction factor test etc. is a significant property for concrete production. Ashok and Sureshkumar [28] assessed red mud's effect in concrete with hydrated lime. They used it up to 20% replacement with cement alongside 5% hydrated lime constant. The increment in slump value was observed with rise in red mud quantity in concrete. True type of slump was found and values of slump lied between 25 to 30 mm.

Red mud used as substitute of cement in different percentage to studied the fresh properties of self-compacting concrete (SCC) by Ghalehnovi et al. [29]. They found descending trend with the increase of replacement ratio. Slump flow diameter was ranged 70 to 80 cm.

Sai and Sukesh [30] determined the workability of concrete containing red mud. Slump value was reduced with increase in red mud in concrete. They concluded that addition of red mud content as substitute of cement was leads to decrease in workability. Similar results also found by Bishetti and Pammar [2] tabulated below in Table 1.

Table 1. Slump value at different percentage of red mud [2]

S. no	Red mud percentage	Slump value (mm)
1	0	65
2	5	61
3	10	60
4	15	55
5	20	51
6	25	47

Tang et al. [31] examined the slump flow of self-compacting concrete (SCC) utilizing red mud as substitute of cement. They observed that diameters of slump flow ranged between 580-630 mm. They concluded that flow ability of modified mixes reduced with the increasing amount of red mud in concrete. This was primarily due to red mud's porous nature which absorbed water and decreased the flow ability [28-29].

3. HARDENED PROPERTIES

The strength and performance of hardened concrete are described in terms of different types of loads and conditions. Main properties which comes under hardened properties are as below.

3.1 Compressive Strength

It is the concrete's property without any cracking or deflection to bear the load on its surface. Metilda et al. [19] studied the concrete's compressive strength on sample size 15×15×15 cm. They obtained highest strength at 15% cement replacement by red mud (Fig. 1). Beyond 15% compressive strength reduced. They suggested that red mud concrete can maintains its strength up to 20% replacement. They conclude that strength was similar to the reference mix at 15% cement replacement. Similar decrement in strength for increment in the content of red mud [30-34]. Similar findings were also reported by other researcher [35-39].

Ghalehnovi et al. [29] analysed the compressive strength of the samples at 3 different curing ages (28, 56, 90days). They observed that, it was decreased in those mixes which had red mud as cement replacement, which is similar to the result of the investigation done by Rathod et al. [11]. The result indicate only 25% red mud substitution of cement was increase strength. They proposed that the optimum substitution of red mud to produce the highest compressive strength of concrete is 25% by weight of cement. The red mud's high fineness is extremely crucial for concrete containing red mud to get a great strength at an initial age of concrete [40-44].

Ashok and Sureshkumar [28] found that the increment in compressive strength with the increment of red mud quantity in concrete. Optimum use of red mud was up to 15% as a cement substitute in concrete, the cost of concrete was reduced to around 7.5% from conventional concrete and compressive strength increased up to 21.7% (Fig. 2). They reported that the decrease in strength was due to the unavailability of the required amount of calcium hydroxide [44-46].

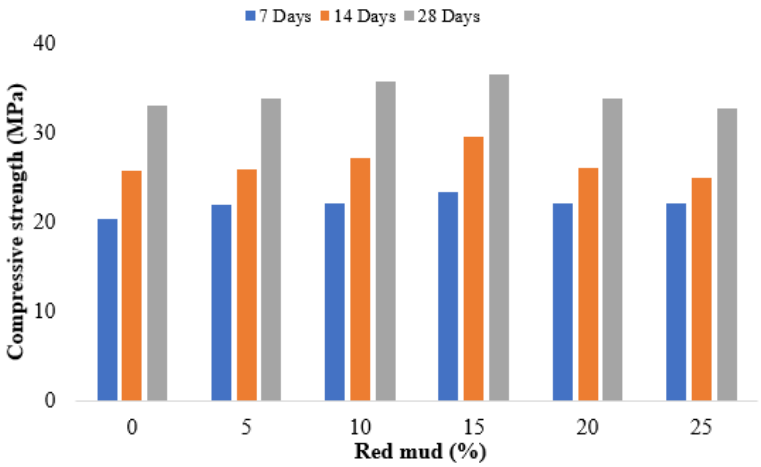

Fig. 1. Compressive strength at various age of curing [19]

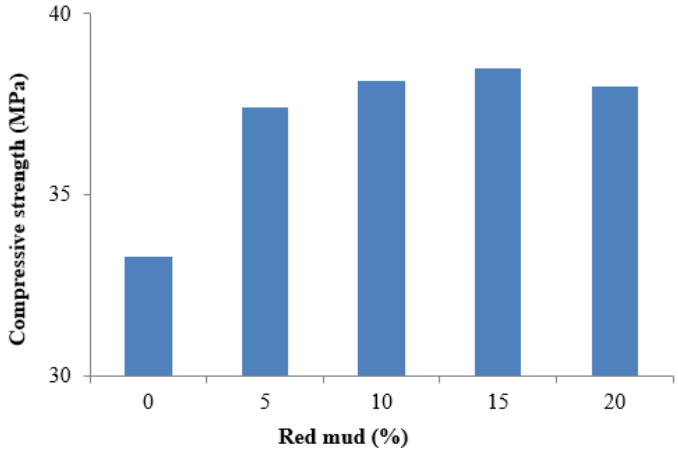

Fig. 2. Compressive strength at different % of red mud [28]

Sethy et al. [18] made concrete which containing (5%, 10%, 15% and 20%) red mud as substitute of cement. Up to 10% substitution of cement the compressive strength of red mud concrete had higher value than traditional concrete but after 10% there was depletion in strength (Table 2).

Bishetti and Pammar [2] analysed compressive strength of concrete containing red mud as partially cement substitute. They reported that strength increased while red mud quantity increased in concrete up to 20%. Further increment tends to decrease the strength. Maximum compressive strength at 7 days was 44.89 MPa and for 28 days it was 52 MPa respectively (Fig. 3). There was a 2.5% to 5% improvement in compressive strength for each percentage replacement. Beyond 20% replacement with red mud the strength decreased [46-49].

Table 2. Compressive strength at different ages

S.no	Mixes	Compressive strength (MPa)		
		3 days	7 days	28 days
1	RM00	10.23	14.73	26.31
2	RM05	12.11	15.40	27.65
3	RM10	13.73	17.67	29.05
4	RM15	10.02	15.20	25.38
5	RM20	8.95	12.68	21.09

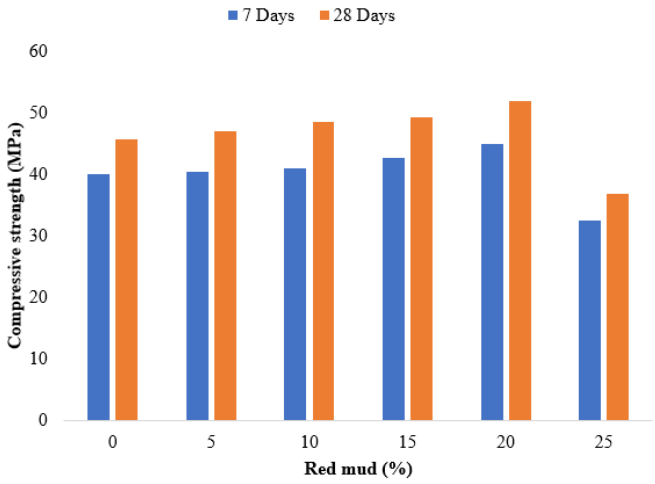

Fig. 3. Influence of red mud in compressive strength of concrete [2]

3.2 Split Tensile Strength

This property refers to the tensile strength of concrete. A split tensile test on the concrete sample is used to obtain it. Cylindrical concrete specimens is used to perform this test.

Tensile strength is particularly most essential properties of concrete since it is weak under tension. The splitting tensile test was conducted on cylinder with dimension of 15×30 cm by Metilda et al. [19]. They found that the highest strength at 15% substitute of cement with red mud. The tensile strength was 4.61 N/mm^2 after 28 days of curing, which is higer than traditional concrete strength. Similar findings also reported by Cholkar et al. [50]. They found that split tensile strength was 3.6 N/mm^2 was higher as compared with 3.25 N/mm^2 for the control mix which is 9.72% more than the normal concrete.

Ashok and Sureshkumar [28] found that the split tensile strength of red mud concrete was increasing with increasing red mud percentage in concrete up to 20%. They said that the proportion of tensile strength was between 10-13% of its compressive strength. Similar finding was also reported by other studies which also showing that the splitting tensile strength of conventional concrete was around 12% of its compressive strength [50-54]. They also presented that best use of red mud was 15% as a partial substitution of cement (Fig. 4). M30 grade concrete with red mud was approximately 7.48% less expensive than the standard concrete. They reported that red mud can be utilize as cement substitute with no adverse effects on the cement's properties, and that it actually enhanced the quality of cement by reducing the setting time and increasing its strength [55-57].

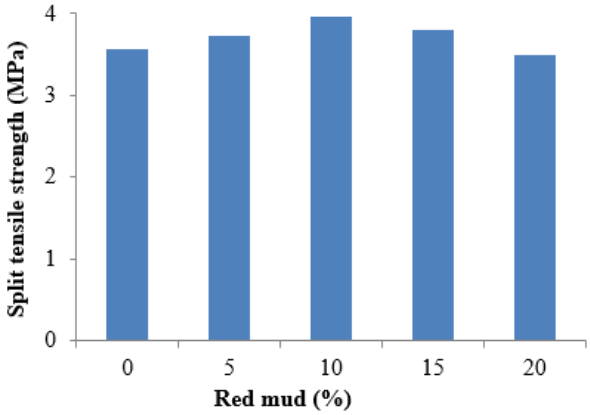

Fig. 4. Split tensile strength at different % of red mud as cement replacement [28]

Sethy et al. [18] examined the tensile strength and it was observed that maximum tensile strength was 3.32 MPa which was came at 10% substitution of cement with red mud (Fig. 5). The splitting tensile strength was recorded to be greater than that of the reference mix, up to 10% red mud, while 15% red mud shows a tensile strength close to that of the reference mix [18]. Similar results showed by other researcher [2,3,58]. For higher replacement levels (more than 15% red mud) the tensile strength reduced as compared with control concrete.

Bishetti and Pammar [2] observed that split tensile strength of red mud concrete tends to reduce with the increase of compressive strength and also with the curing age. The finding was also confirmed by previous studies. Rathod et al. [11] showed similar results in which tensile strength decrease with increment in red mud percentage in concrete. The study showed decreased in split tensile strength as increase red mud content as substitution of cement in concrete [59-63].

3.3 Flexural strength

Flexural strength is the bending stress of material strength before the yields in a bending test. Metilda et al. [19] investigated concrete's flexural strength which was improving with the addition the red mud quantity as cement substitute in concrete. Flexural strength was increasing from the reference mix up to 20%. They found optimum replacement was 15% for flexural strength (Fig. 6). Similarly flexural strength was higher with respect to the control mix which is 15.56% more than the normal concrete were also found by Cholkar et al. [50].

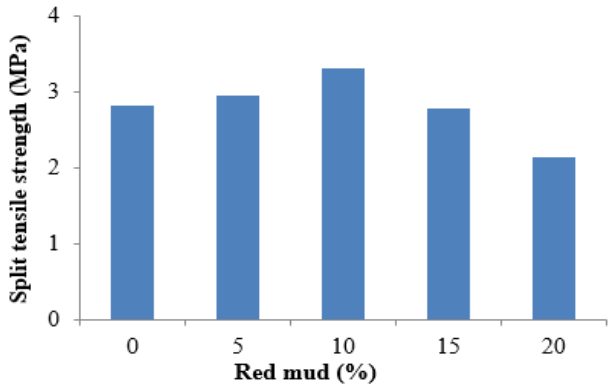

Fig. 5. Split tensile strength results [18]

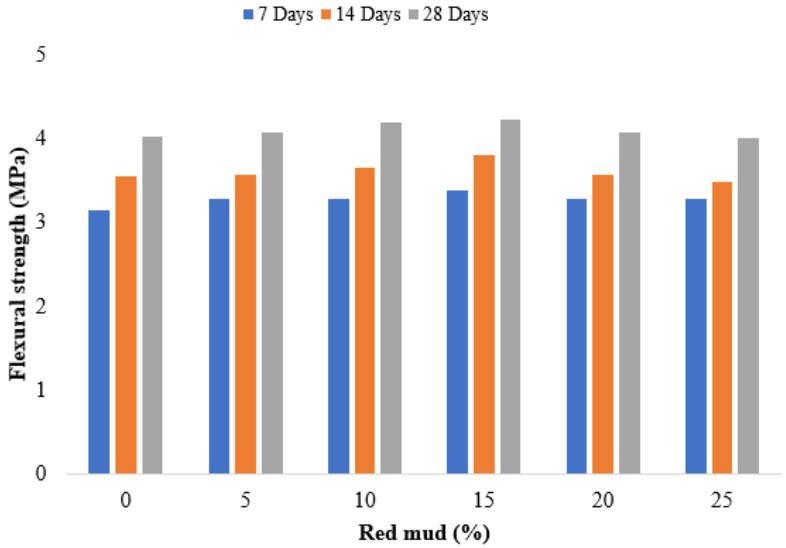

Fig. 6. Flexural strength at different ages [19]

Viyasun et al. [64] conducted a study to find the flexural strength of red mud concrete. They found that the flexural strength's value was increased with time and results clearly indicated that slightly replaced cement by red mud up to 30% in concrete shows higher value than the conventional concrete.

Ashok and Sureshkumar [28] casted beam of size 100×100×500 mm for flexural strength test. They reported that the flexural strength increased maximum up to 15% red mud substitute in concrete with cement. Ultimate flexural strength at 15% replacement was 92 KN (Fig. 7). Further increase in red mud amount as substitute of cement in concrete leads to decrease in flexural strength [50,51].

Palaniappan et al. [65] noticed that the flexural strength of concrete containing red mud as cement replacement was increasing with the rise in red mud quantity in concrete. They observed that flexural strength was 21.6 KN, 23.4 KN and 16.3 KN at 5%, 10% and 15% replacement respectively. So they presented that ideal replacement of cement by red mud was up to 10%.

3.4 Water Absorption

A water absorption test is conducted to check the amount of water absorbed by concrete, it also reveal the existence of pores inside the concrete. Viyasun et al. [64] carried out a research study on concrete containing red mud and they found that the water absorption reduced with increment in amount of red mud on concrete. Water absorption % was found 1.55%, 1.2%, 1.08% and 0.97% respectively at 0%, 10%, 20% and 30% of red mud.

Ghalehnovi et al. [29] investigated the water absorption at different percentage of red mud in concrete. Water absorption percentage ranged from 1.8% to 2.2% after 28 days and from 2.1% to 2.9% after 90 days, according to the researchers. They reported that when red mud was taken as cement replacement, the water absorption values were nearly identical to those of the control mix, with differences of just 1.15%, which is negligible.

Venkatesh et al. [66] observed that use of red mud in concrete reduce the water absorption with the rise of red mud in the substitution of cement. The findings show that as the curing age increases and the substitution level increases, the water absorption values decrease (Fig. 8). They reported reason for decreasing water absorption was the very small particles of red mud, which sealed every cracks and pores that presented in the concrete.

3.5 Modulus of Elasticity

The elastic modulus of an object is a measurement of its resistance to being elastically deformed when stress is applied. Ghalehnovie et al. [29] analysed the modulus of elasticity of self-compacting concrete (SCC) having red mud as substitution of cement. They found that reference mix has the biggest value, which reduced as the red mud amount increases. The best results came from the RF25 mix (25% red mud), which had a modulus of elasticity of 32 GPa, which was similar to the reference mix's 33 GPa (Fig. 9).

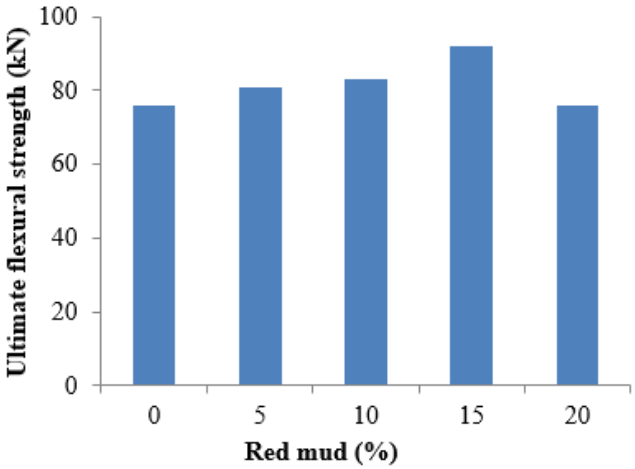

Fig. 7. Flexural strength results [28]

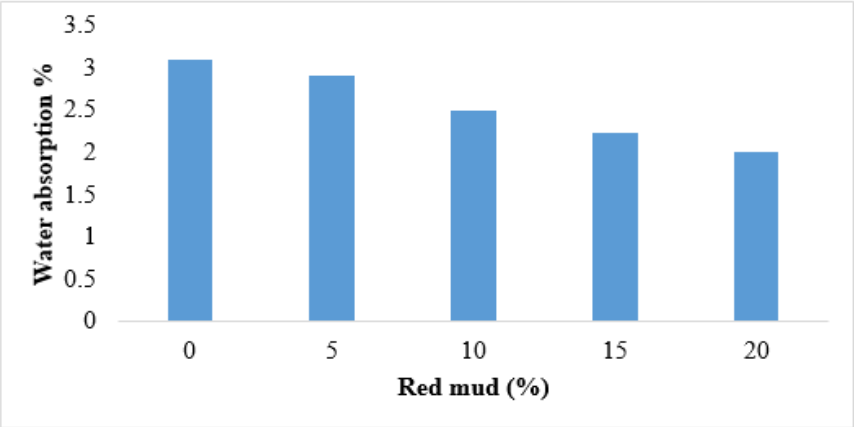

Fig. 8. Water absorption at different % of red mud containing concrete [66]

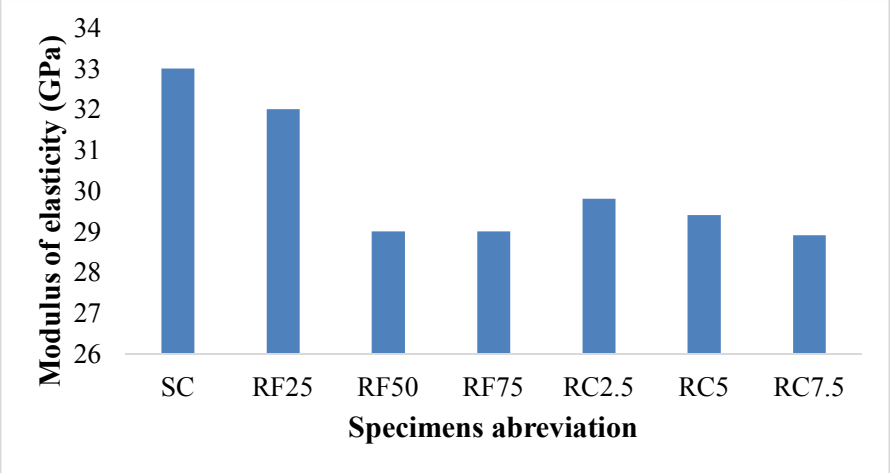

Fig. 9. Modulus of elasticity of different mixes [29]

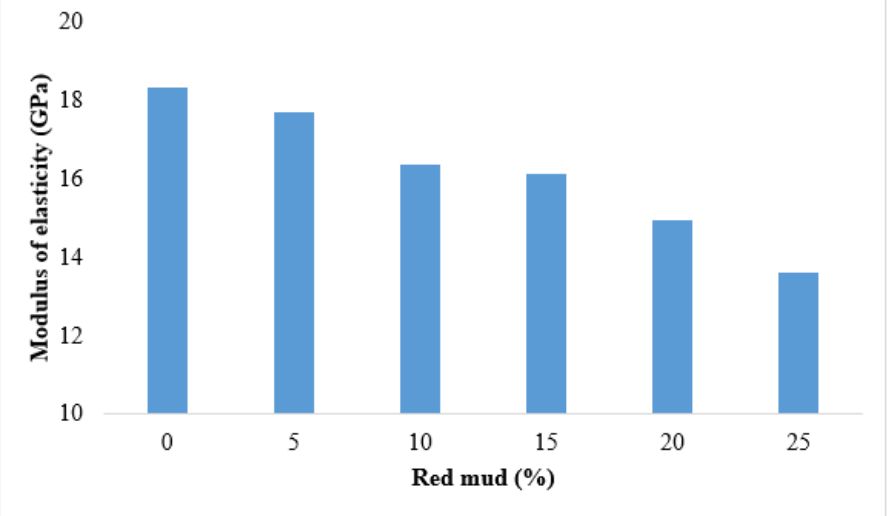

Fig. 10. Influence of red mud on modulus of elasticity [23]

Liu et al. [67] analysed the modulus of elasticity (MOE) on self-compacting concrete (SCC) containing red mud. They noted that increase in red mud quantity which was 0% to 30%, the MOE was continuously increase. Maximum modulus of elasticity was found at 30% replacement after that decreased in it.

Nikbin et al. [23] found that concrete's modulus of elasticity (MOE) was reduced by adding red mud as substitute of cement. At red mud content increased as 5%, 10%, 15%, 20% and 25% as replacement of cement, MOE was reduced by 3%, 11%, 12%, 18% and 26% respectively as related to the controlled mix sample (Fig. 10). The explanation they quoted for the decrease in modulus of elasticity was due to the fact that the increment of red mud reduced aggregate volume in the mix, resulting in lower stiffness in the concrete mix.

4. CONCLUSION

In present time the consideration of sustainability is needed in construction activities. In the past, several studies were conducted on the different materials to replace cement in concrete. In this study, the effect of red mud on properties of concrete such as fresh, mechanical and durability are presented. The attempt has been made to review red mud and its influence in concrete as cement replacement.

Based on a thorough analysis of the works reported, the following conclusion can be drawn:

- Based on the various research article results subjected to various red mud percentage in concrete, it can be concluded that the optimum utilization of red mud will be up to 15% by weight of cement in concrete.
- The fresh properties of the red mud concrete has different results, some researcher reported increase in workability with increase in red mud amount in concrete, some presented reduction in workability as red mud percentage increase in concrete.
- From the above study, we can say that increment in compressive strength while increase in red mud quantity up to 15 percentage, after that it reduced as the percentage of red mud increased in concrete as cement replacement.
- Various study showed that there was enhancement in flexural strength just like compressive strength up to 15 percentage of red mud content, after that limit it also got reduced as red mud content increase in concrete.
- As the proportions of red mud increased to a certain limit, the split tensile strength increased. Optimum replacement of cement was around 15 percent by red mud after that strength decreased.
- Water absorption decreased with the increase in red mud content in concrete. It means the durability properties of concrete improved by red mud.
- Modulus of elasticity reduced with the increase in red mud content in concrete.

Concrete with red mud as substitute is sustainable construction material which decrease pollution as well as disposal related issues which is harmful of environment. The optimum substitution level of cement with red mud was found to be 5-15%. Using red mud clearly enhanced the mechanical properties and durability properties of concrete.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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