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Experimental Study on the Mechanical Properties of Sustainable Concrete using Recycled Plastic and Glass Waste

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Abstract:- This study explores using recycled waste glass and plastic fibers as substitutes for fine aggregates in concrete to meet the growing need for sustainable building materials. The basic materials consist of OPC 43 grade and locally obtained river sand. The research incorporates glass powder from crushed beer bottles and plastic fibers from recycled plastic bottles into the concrete mixture. Various tests, including slump, compressive strength (CS), and split tensile strength (STS) assessments, are performed to ascertain the characteristics of the modified concrete in both its fresh and hardened states. The findings demonstrate a significant enhancement in the ease of handling when glass powder is used, exhibiting a surge of 170% and 270% for mixtures, including 15% and 25% glass powder, respectively, compared to conventional OPC concrete. Although including these recycled materials reduces compressive strength (19.95% for SP15 and 21.39% for SP25); tensile strength is significantly improved, with gains of 35% for SP15 and 53.75% for SP25. This research emphasizes the feasibility of integrating waste glass and plastic fibers into concrete as a practical method for sustainable building.

Keywords:- *Green Concrete, Waste Glass, Split Tensile Strength, Compressive Strength, Plastic Fiber.*

➢ ***Nomenclature:***

- ***STS = Split Tensile Strength***
- ***OPC = Ordinary Portland Cement***
- ***OC = Ordinary Concrete***
- ***SP15 = Special concrete having 15% of glass powder***
- ***SP25 = Special concrete having 25% of glass powder***
- ***WGP = Waste glass powder***
- ***MSW = Municipal solid waste***
- ***WEP = Waste Electronic Plastic***
- ***CS = Compressive Strength***

I. INTRODUCTION

With the rise in population, the construction sector is witnessing a significant rise in concrete demand for infrastructure development, as it is one of the mainstays of the construction world [1]. The essential materials for making concrete, including cement and fine and coarse aggregates, have been overexploited leading to environmental concerns and unsustainable extraction of fresh natural materials. It is estimated that the global consumption of concrete amounts to around twenty billion metric tonnes annually. A total of 14 billion metric tonnes of natural aggregate is necessary to facilitate the production of this quantity of concrete. Not only does the manufacturing of concrete adversely affect the environment, but its disposal is also a key concern. Based on the current investigation, annually, the global population faces the challenge of handling 615 million metric tons of demolished concrete waste, also known as the construction and demolition of C & D waste [2]. India is projected to produce around 300 million tons of municipal solid waste (MSW) annually by 2047. Adopting eco-friendly substitutes that minimize the impact on the environment by allowing materials that can be recycled to be integrated into concrete has found increased interest and widespread adoption in different parts of the world [3]. Recently, several sustainable materials, including plastic [4], glass waste [5], industrial and agricultural waste [6][7], C & D waste [8][9] have been employed to reduce the proportions of cement and sand in concrete and also minimizing the waste disposal requirements. Integrating recycled glass and plastic waste can effectively mitigate landfill issues, decreasing environmental impact [10]. Recently, the partial replacement of cement and sand with plastic and glass has become more prevalent in sustainable practices. Several research efforts have been implemented in the past few years to examine recycled crushed glass as an ingredient in concrete [11] [12] [13]. Furthermore, using glass as a partial replacement of sand in fresh concrete increased workability due to its smooth surface and less water absorption. In contrast, glass sand has been shown to enhance the resistance to chloride ion penetration, and inconsistent findings about the impact on hardened

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concrete's mechanical and durability qualities are evident [14]. Researchers have investigated waste glass powder (WGP) to replace sand and cement in concrete and found that using WGP at specific concentrations significantly improved compressive strength, simultaneously allowing sustainable concrete construction. The effect of combining Waste Electronic Plastic (WEP) and WGP in concrete has also been investigated [15]. The study observed that including fractions of WGP and WEP significantly improved compressive strength and an equivalent reduction in porosity. Similarly, authors have incorporated waste rubber and glass powder into concrete and observed that adding 10% and 20% rubber enhanced strength, while combining rubber and glass powder improved workability due to a synergistic effect [16]. Similarly, Tamanna et al. [17] stated that replacing natural river sand with recycled glass at different proportions significantly increased the strength of concrete. The substitution considerably increased the structural strength with the ability to resist chloride attack. Likewise, Baikerikar et al. [18] evaluated replacing cement with glass powder from 5% to 25% in 5% intervals and assessed substituting glass powder for cement at intervals of 5% to 25% and waste glass sand for fine aggregate at intervals of 10% to 50%. They concluded that introducing 5% glass powder and 10% glass sand to concrete enhances its strength, durability, and water resistance. In the same way, Hamada et al. [19] highlighted the beneficial environmental implications of reducing carbon emissions using waste glass aggregate. They suggested replacing a proportion of the fine aggregate in concrete with crushed waste glass ranging from 20% to 30% and substituting a portion of the coarse aggregates with 10% to 20%, eventually increasing mechanical strength and durability. Similarly, Harrison et al. [11] investigated replacing cement or fine aggregate with waste glass. Their results imply that 20-micron waste glass particles may replace up to 20% of cement without altering mechanical qualities. However, a 20% acceptable aggregate replacement compromised mechanical and fresh concrete attributes. The result might be because glass possesses less specific gravity than natural sand. Similarly, Ma et al. [20] examined concrete mix in the ratio of 10%, 20%, and 30% sand, rubber, and coarse aggregate, respectively, with glass. They noticed a substantial increase in water permeability and decreased water absorption in concrete. Further, the waste rubber and glass enhanced rubber concrete's strength, with 10% and 20% waste rubber and glass yielding the best results. Likewise, Al-Awabdeh et al. [14] concluded that substituting fine aggregate with glass waste particles reduced water absorption in concrete mixes. Replacement of fine or coarse aggregate with 50% unprocessed glass waste increased CS by 29% at seven days. However, replacing coarse aggregate with 30% and 50% untreated glass reduced compressive strength by 7% and 33%, respectively. Notably, 30% and 50% of untreated fine glass mixes showed greater splitting tensile strength.

In underdeveloped countries, waste generation rises parallel with population growth, and solid waste like glass, plastic, polythene, etc., needs to be managed appropriately. Additionally, the adoption regular concrete mix is prevalent for residential construction using industrial waste [21] [22]. In various research studies, wastes like rice husk, glass powder, foam, etc., were used in concrete, but many researchers have used waste as binding material like cement. Utilizing waste material as a filler, like partial replacement of sand, is also highly advantageous because the characteristics of glass powder are comparable to fine aggregates, like the specific gravity and size of the particle [23][24][25]. Replacing coarse aggregate with glass powder offers a sustainable strategy while addressing waste challenges and enhancing concrete structural and mechanical features. Several researchers have studied concrete's fresh and hardened properties by incorporating glass and plastic waste, yielding distinct results in which some exhibited positive while others reported adverse impacts [26][27][28][29]. This study aims to comprehensively analyze the combined effect of glass waste and plastic fiber in concrete mixes. It is evident that by adding glass and plastic waste to ordinary concrete, construction expenses may be significantly lowered, and methods for managing solid waste can be enhanced as a solution to the challenges posed by a growing population with a lack of infrastructure for waste disposal. This research investigated the long-term sustainable solution of filler material by integrating glass and plastic waste into concrete. Further, this study assesses the freshness properties by slump test, hardness properties of regular concrete by strength tests, and the viability of utilizing glass and plastic waste in concrete with different proportions.

II. MATERIALS AND METHODS

The methodology involves collecting constituent materials like fine and coarse aggregate, cement, and supplementary waste materials such as plastic and glass waste. Afterward, the study focuses on the mixed design of the concrete preparations. After preparing the design mix, the samples are cast, cured, and further tested. The tests include the fresh and hardened properties of the concrete, such as slump, density, compressive strength, and split tensile strength (STS). Discussion and conclusions are based on partial replacements in fine aggregate by glass waste in different percentages.

A. Materials

- *Cement*

Ordinary Portland cement is most prevalent in the market, exhibiting high familiarity and availability. The study used OPC 43 grade for its experimental work. The cement's physical qualities are evaluated as per the established standard process, verifying its compliance with the specifications given in IS 12269:1989. The physical characteristics of the cement are shown in Table 1.

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Table 1: Physical Properties of Cement Used

S. No	Test	Results
1	Initial Setting Time	35 minutes
2	Final setting Time	517 minutes
3	Specific Gravity	3.14
4	Fineness by Sieving	6%
5	Normal Consistency	31%

➢ *Fine Aggregate*

The sand used is locally available river sand that complies with the specifications of IS 383:2016, which includes passing through a 4.75 mm screen. As per the lab test, the fine aggregate has a gravity of 2.55, dry density of 1650kg/m3, water absorption of 1%, and moisture content of Nil. The fine aggregate is classified as Zone II based on the findings of the sieve analysis, which indicates the presence of medium sand.

➢ *Glass Powder*

Incorporating glass powder as a partial replacement for fine aggregate in concrete mixes is widespread [17]. Beer bottles were salvaged from a dumping site and sterilized with warm salty water to remove unwanted contaminants and the presence of oil. In a controlled laboratory setting, the bottles are crushed manually using rammer and crushed glass powder as shown in Fig. 1, decreasing the resulting dimensions to less than 2.7 mm. In addition, the material obtained had a specific gravity of 2.5, which meets the requirements of gradation zone II as stipulated in the IS 383-2016 standard. A sieve analysis determined this conformance.

Fig 1: Glass Waste Powder Sample Preparation

➢ *Coarse Aggregate*

The coarse aggregate selected for this study was from the Manahara River site, which entails considering several fundamental properties. These properties include strength, impermeability, durability, and the ability to generate a workable mixture with the lowest possible water-to-cement ratio, consequently ensuring adequate strength. The use of coarse material that is readily accessible and retained on a 4.75 mm sieve is employed. As per the lab test, the coarse aggregate has a gravity of 2.7, dry density of 1850 kg/m3, water absorption of 0.73%, and moisture content of Nil. Based on the sieve analysis, it is determined that the combined aggregate consists of coarse aggregate with a nominal size of 20 mm.

➢ *Superplasticizer and Supplementary Plastic Waste*

Superplasticizers are used in both ordinary and extraordinary concrete. It is used up to 1% of cementation materials to increase the workability of concrete, and the density of the superplasticizer is 1.18 kg/l. Plastic fiber is used as an additive in specialized concrete compositions. Mineral water bottles were retrieved from the Sisdol dumping site and subsequently cleaned. Such bottles are hand-cut, with widths varying from 4 to 6 millimeters and lengths ranging from 10 to 12 millimeters, and mixed as plastic fibers in the concrete mixture at 250g/m3 in concentration. This results in improved tensile strength without adversely compromising the compressive strength [30].

B. Mix Proportion and Design

The study utilized a concrete mix design that included converting density to mass. This process resulted in a water-cement ratio of 0.54. M20 grade of concrete is used for this study as it is the most commonly used mix for building construction in Nepal. Three specimens are prepared that are ordinary concrete (OC), and special concrete having 15% and 25% of glass powder (SP15) and (SP25) respectively. The requirements for the concrete mix design are as follows: The composition consists of 308 kg/m3of cement, 706 kg/m3 of fine aggregate, 1240 kg/m3of coarse aggregate, 168.833 kg/m3of water, and 3.08 kg/m3 of chemical admixture. The ratio of cement to fine aggregate to coarse aggregate was calculated to be 1:2.29:4.02 in compliance with IS 10262:2019. The computed amounts of concrete ingredients are estimated and shown in Table 2.

Table 2: Materials Content for 1 m^3 of Concrete Mixture

Specimen	Cement (kg)	Fine Aggregate (kg)	Glass Powder (kg)	Coarse Aggregate (kg)	Water (L)	Plastic Fiber (kg)	Superplasticizer (l)
OC	308	706	-	1240	166.32	-	2.61
SP15	308	600.4	105.6	1240	166.32	0.25	2.61
SP25	308	529.5	176.5	1240	166.32	0.25	2.61

The purpose of this study was to evaluate the compressive and split tensile strengths of concrete that has waste glass substituted for part of the fine aggregate. Compression testing equipment was used in the laboratory trials to test the compressive strength and split tensile strength of cube and cylindrical specimens. Each batch underwent testing with three samples, and the average strength findings were used. The M-20 concrete mixture

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was modified by replacing natural fine particles with 0%, 15%, and 25% of glass powder. A cube with a 150 mm side dimension and a cylinder with a diameter of 150 mm and a height of 300 mm are used, after a 7-day and 28-day curing period, for strength measurements. The slump values were used to evaluate the workability of recently manufactured concrete. The concrete components were rigorously blended until a uniform consistency was attained. A vibrating table was used to compact the cubes and cylinders. A comparison is made between the data obtained from concrete specimens with glass waste powder substituted for fine aggregate and the data from regular concrete, without any waste material replacement.

III. RESULTS AND DISCUSSION

Fresh concrete can be molded in any desired shape because, at this point, it is still plastic and workable. Likewise, the state at which concrete reaches after setting and curing is known as hardened concrete. After the freshly prepared concrete was completed, a slump cone test was subjected to assess the fresh properties. At the same time, the compressive testing machine was introduced to assess different strengths, including compressive and splitting tensile, as shown in Fig. 2.

A. Fresh Properties

The measure of the fluidity of a mixture is workability. A slump cone, a height of 30cm, is used to evaluate the feasibility of mixes. The experimental results show that the amount of glass powder and the material's workability are positively correlated. The compact surface roughness of the glass particles could be responsible for the mixture's improved workability.Moreover, it was discovered that adding plastic fibers improved the mixture's workability slightly. There has been a noticeable difference in slump values according to the concentration levels of glass powder.

Fig 2: Fresh and Hardened Properties Test (a) Workability Test (b) Prepared Specimens (c) Compressive Strength Test (d) Splitting Tensile Strength Test

The OC sample, which had 0% glass powder, had a slump value of around 10 mm, but the SP 15 and SP 25 samples, had a slump measurement of 27mm and 37mm respectively.As the proportion of glass powder increases, the slump value of samples, SP 15 and SP 25 increase by 170% and 270% respectively compared to the OC sample. A Study by Abhijeet Baikerikar et.al [18] has shown that as compared to fine aggregate, glass powder has a much lesser potential to absorb water. This previously addressed situation suggests that more pertinent factors, including particle characteristics, dispersion, and potential pozzolanic reactions, significantly improve workability and water absorption.

B. Strength Properties

- *Compressive Strength Test*

The primary concern in concrete is compressive strength since its structural application is significantly influenced by hardened properties. The concrete sample compressive strength at both 7 and 28 days, shown in Fig-3, showed an apparent decrease with glass waste, particularly with the addition of superplasticizers. Specifically, at seven days, the compressive strength decreased by 8.40% with SP15 samples and 19.63% with SP25 samples compared to OC. This trend continued at 28 days, where the compressive strength dropped by 19.95% with

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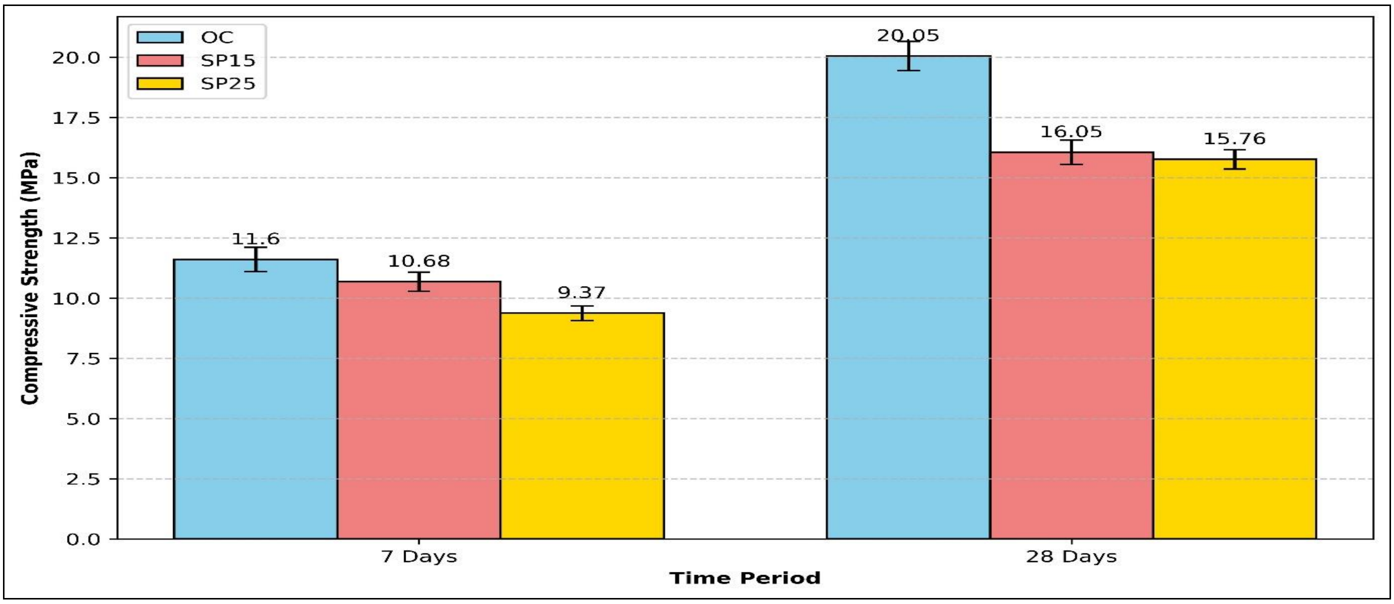

Fig 3: Compressive Strength of Different Concrete Specimens in 7 and 28 Days

SP15 and declined by 21.39% with SP25 as compared to OC. The observed decrease in compressive strength can be attributed to the smoother surface texture of glass grains in contrast to conventional sand particles. This smoother surface results in a weaker bond within the concrete matrix [31] [32]. The findings reveal a direct correlation between the reduced compressive strength and the difference in surface textures. This illustrates that including glass in the concrete mix leads to a compromised bond strength within the concrete structure. The presence of glass powder as a partial replacement of sand in concrete makes weaker bonds due to its smooth texture compared to sand, so fewer cracks are shown in OC. As a result, when the percentage of glass powder increases, the number of cracks increases in SP 15 and SP 25, respectively. The crack pattern at breaking load is shown in Fig. 3, where Fig. 4(a) represents OC, Fig. 4(b) represents SP15, and Fig. 4(c) illustrates the SP25 mixture.

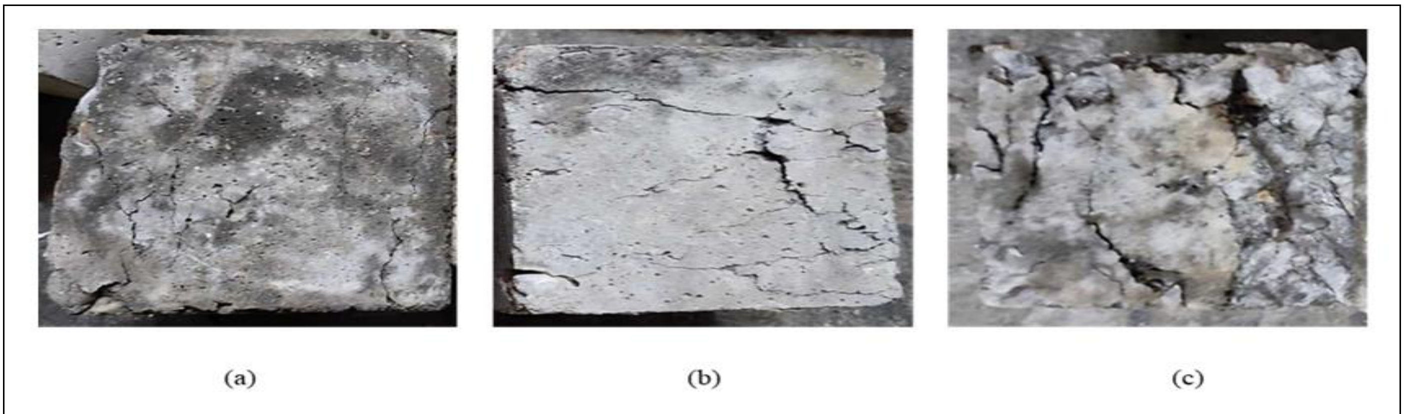

Fig 4: Crack Pattern (a) OC (b) SP15 (c)SP25

➢ *Split Tensile Test*

The result after investigations by including additives like plastic fiber and glass powder affected the splitting tensile strength of the concrete, as shown in Fig-5.The result after investigations by including additives like plastic fiber and glass powder affected the splitting tensile strength of the concrete, as shown in Fig-5.SP15 showed a notable increase of 35% in splitting tensile strength. SP25 exhibited an even more significant surge of 53.75% compared to ordinary concrete (OC) in the study conducted on 28-day cured cylindrical samples. Despite having the same amount of plastic fiber in both samples, SP25 had a higher tensile strength than SP15. This observation highlights the additional importance of glass powder for enhancing the tensile strength of concrete. The results strongly imply that the concrete mix containing plastic fiber and glass powder significantly increases the material's tensile strength. The plastic fiber content of the specimens, SP 15 and SP 25 remain constant at 250 gm/m3 of concrete; it may be inferred that glass powder is the cause of the rise in split tensile strength. For SP 15 and SP 25, the 28-day CS is 16.05 MPa and 15.76 MPa, respectively. It can, therefore, be applied to construction projects requiring a moderate level of strength. Based on the results, M15 can be ideally substituted with SP 15 and SP 25, providing better tensile strength and enhancing crack resistance, which can be used for PCC, beams, lintels, flooring, and other general building applications.

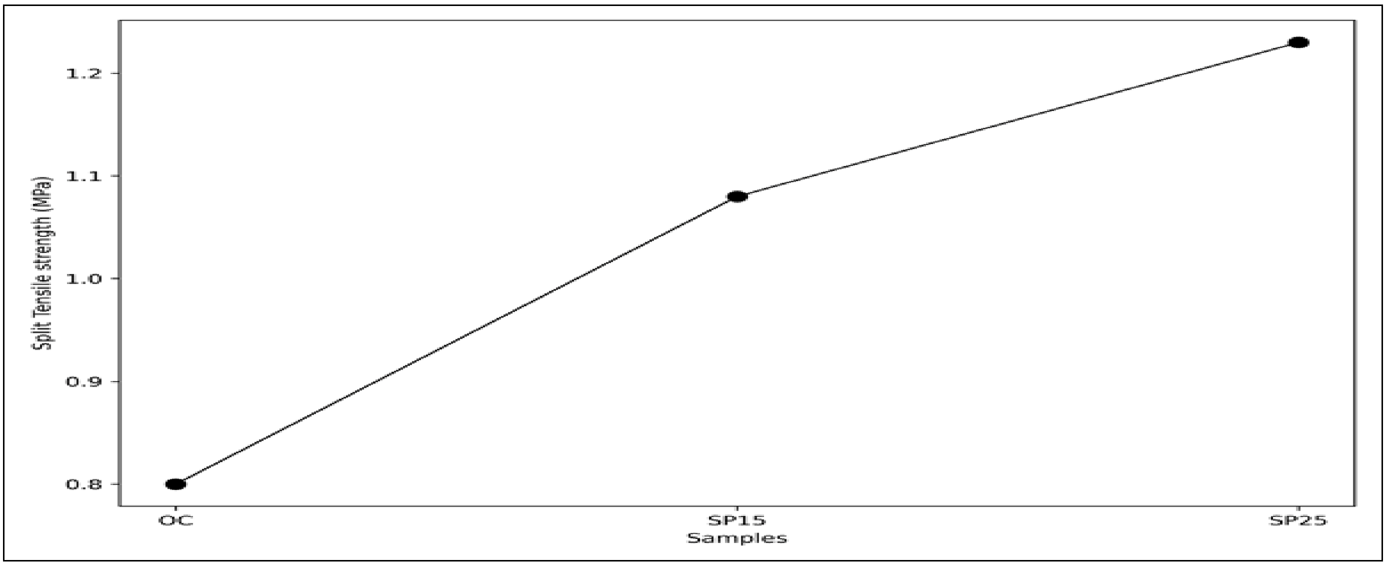

Fig 5: Splitting Tensile Strength of Different Concrete Samples

C. *Comparative Sieve Analysis of Glass Powder and Sand*

The sieve analysis of sand and glass powder, shown in Fig-6 provides valuable insights into their corresponding fineness properties, which subsequently impact the strength of concrete.

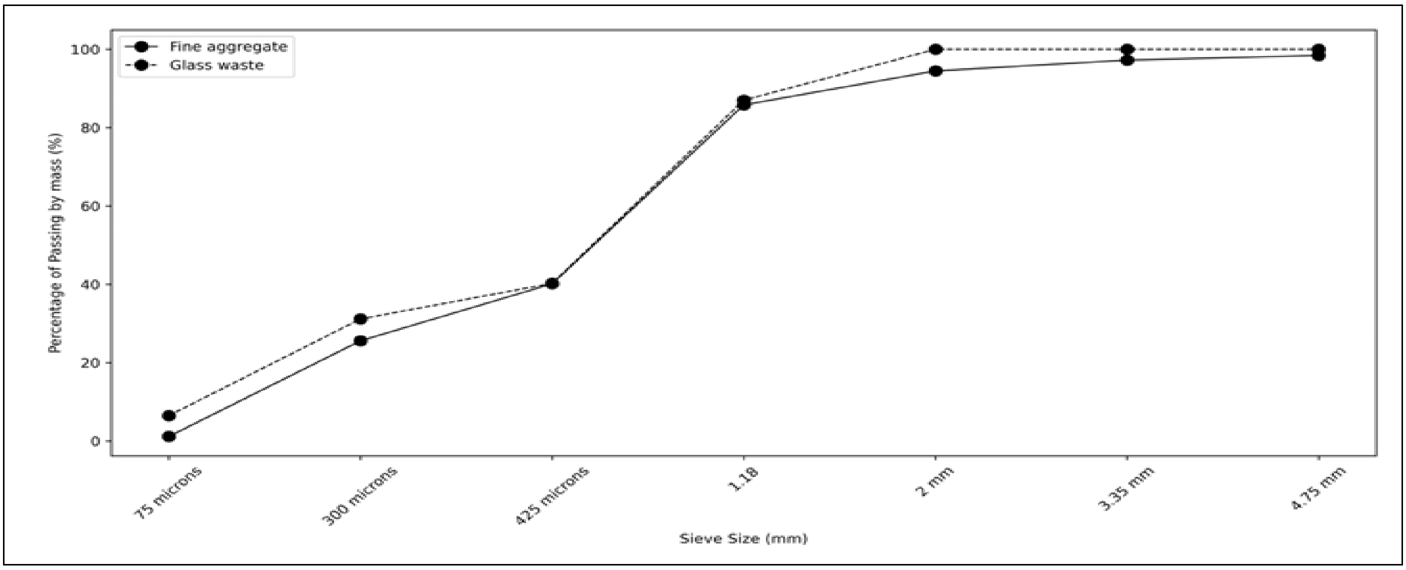

Fig 6: Particle Size Distribution of Fine Aggregate and Glass Waste Powder

The glass powder demonstrates a more significant permeability percentage than sand within the size range of 4.75mm to 1.18mm and, subsequently, from 425 to 75 microns. The results suggest that the glass powder has a more refined consistency, characterized and distinguished by smaller particles that exhibit a higher rate of passing via sieves than bigger particles of sand. The differences in the level of fineness impact the fineness modulus, a quantitative measure utilized for evaluating the fineness of aggregate materials in concrete. Moreover, an intriguing consistency is seen across the size range from 1.18mm to 425 microns, where both glass powder and sand demonstrate the same proportion of passing. The balance in segregating particles suggests that the two components possess comparable levels of refinement within this range. The fineness modulus, established based on the particle size distribution, signifies the optimal fineness in the concrete mixture. The equilibrium is crucial for comprehending the components' contribution to the concrete's total strength.

IV. CONCLUSION

It is pertinent to adopt a sustainable construction practice incorporating waste materials such as glass and plastic waste to partially replace fine aggregate, eventually reducing the impact on the limited natural resources. Integrating such waste without adversely compromising the performance of the overall concrete makes an ideal choice for adoption. Plastic and glass waste offer several advantages that improve the concrete’s tensile strength. However, the selection of glass type, particle size of glass and plastic waste, and replacement percentage of waste glass play a pivotal role in governing the strength of the concrete. The present study utilized 15% and 25% waste glass powder to replace fine aggregate in concrete. Furthermore, the study adopted the replacement percentage by adding 250 gm/m3 of plastic fiber. The results prove that the mixtures of concrete adding 15% and 25% glass powder demonstrated an incredible 170% and 270% rise in workability, respectively. This indicates that adding glass powder to concrete improves its workability. Likewise, compared with ordinary concrete, the split tensile strength of SP15 and SP25 increased by 35% and 53.75%, respectively. However, it is noticed that a significant 19.95% and 21.39% decrease in compressive strength was reported in SP15 and SP25, respectively. As a result, through this study, it can be concluded that SP15 and SP25 are not viable options for replacing M20. However, as the 28-day CS for SP 15 and SP 25 are 16.05 MPa and 15.76 MPa, respectively, it can be utilized in projects requiring a moderate amount of strength. According to the findings, SP 15 and SP 25 could be suitable alternatives for M15 in terms of tensile strength and crack resistance. These materials can be utilized for PCC, beams, lintels, flooring, and other general building applications. Furthermore, the presence of glass powder, which has a nice texture and may be employed in ornamental and decorative buildings, improves the appearance of the concrete surface. By using the green construction approach, we may lessen our reliance on natural resources like fine aggregate and cement, which will positively influence the environment.

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