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Assessment of Workability, Compressive Strength, and Tensile Strength of Fly Ash-Glass Waste Fiber-Reinforced Geopolymer Concrete with Recycled Steel Can Fibers

Louis M. Wong IV[1], David Andrew M. Balingit[1], Michael Joshua B. Espiritu[1], Edgardo S. Cruz[1]
[1]Mapúa University
658 Muralla St, Intramuros, Manila, 1002 Metro Manila, Philippines
limwong@mymail.mapua.edu.ph, dambalingit@mymail.mapua.edu.ph,
mjbespiritu@mymail.mapua.edu.ph, escruz@mapua.edu.ph

Abstract **-** Concrete plays a vital role in civil engineering and infrastructure development. As the focus shifts toward sustainable practices, innovative approaches such as geopolymer concrete and glass waste as aggregates have emerged, improving both the environmental impact of concrete and its mechanical properties. Fiber reinforcement, especially with recycled materials, is gaining attention to enhance the sustainability of concrete, with commercial storage materials such as steel cans becoming viable materials to be used in reinforcement. This study examined the workability, compressive strength, and tensile strength of fly ash-glass waste fiber-reinforced geopolymer concrete (FRGC) using recycled steel can fibers. Samples were produced by crushing soda-lime glass bottles and cutting steel cans into hook-end fibers, with an M20 concrete mix formulated by substituting 30% cement with fly ash and 30% coarse aggregates with glass waste. Recycled steel can fibers were added at varying percentages (0-5% by weight of cement). Results showed a decrease in workability as recycled fibers were added. While compressive strength also decreased, the reduction was insignificant at 4% fiber content. Adding fibers improved tensile performance in terms of tensile strength, though it remained insignificantly different from the control group. Notably, samples of concrete containing recycled steel can fibers exhibited ductile failure and fiber bridging. Overall, the fly ash-glass waste FRGC with 4% recycled steel can fiber demonstrated favorable outcomes in compressive and tensile strengths. This study highlights the potential of using recycled steel cans to enhance concrete sustainability.

Keywords**:** fiber-reinforced concrete (FRC), geopolymer concrete, recycled fibers, workability, compressive strength, tensile strength

1. Introduction

Among the many innovations in the civil engineering industry, concrete remains one of the constant elements used to create different structures. Concrete became one of the principal building materials in structures due to its price, compressive strength, weathering fire resistance, and formability [1]. It can withstand tensile stress upon pairing with reinforcements such as steel bars, making reinforced concrete a reliable building material that offers durability, strength, versatility, and cost-effectiveness. This led to reinforced concrete commonly applied to existing buildings and infrastructures such as bridges, flyovers, roads, and marine structures [2]. While Ordinary Portland Cement became the standard choice for concrete, experts remained open to choices regarding economy, design, and the recent promotion of sustainable practices, and Geopolymer concrete has become a significant interest in the civil engineering industry.

Geopolymer concrete is a special type made by combining aluminate and silicate-bearing materials through a caustic activator [3]. After several studies exploring the mechanics and potential application of Geopolymer concrete, engineers could incorporate the concrete into their practices, rendering it better than OPC in several factors. One of the benefits of geopolymer concrete is its substantially lower carbon dioxide emissions, which are a significant issue in the production of OPC, in addition to its demonstrable increase in strength and workability [4]. Geopolymer concrete is preferred over OPC, which uses a lot of natural resources because it uses either organic materials or industrial waste. As concrete became more utilized in the industry, studies were conducted regarding innovations. Glass waste is another concrete component that can be utilized as aggregates in concrete. These glass wastes usually come from beverage bottles that are made up of soda-lime glass. Glass waste can become compatible with concrete when partnered with fly ash, another more sustainable material for concrete mixes [5]. In addition, glass waste is also known to be better in terms of abrasion resistance than mineral aggregates.

The introduction of fiber-reinforced concrete helped introduce more sustainable options, like the use of recyclable fibers. Using recycled fibers for fiber-reinforced concrete (FRC) has been a topic of interest for years, and researchers and scholars are finding ways to reuse waste products in the construction field. Steel cans are one of the most common materials people see in households as they are used as containers for food, oil, chemicals, and others. Steel cans are said to be 100% recyclable due to their material, yet according to the Environmental Protection Agency (EPA), only an estimated 73.8 percent of the generation of steel cans is recycled. Steel cans are often confused with tin cans/aluminum cans due to their similar function and physical properties [6]. However, steel cans are usually containers of food products that are mainly made up of steel, with tin only serving as the coating for the steel cans [7]. This means that steel cans mainly possess the mechanical properties of steel and not that of tin. In addition, steel cans are different from cans that contain drinks and beverages since these beverage cans are commonly made up of either aluminum or tin. The relevance of using steel cans in construction is given by several favorable mechanical properties of steel cans, which include axial resistance or resistance from loads, radial resistance or resistance from external pressure, and resistance to deformation due to internal pressure [8]. Additionally, adding these steel cans to concrete enhances its mechanical qualities and inhibits corrosion [9]. The suitability of steel cans in construction due to their apparent mechanical properties and being recyclable makes them highly economical and environmentally friendly materials with great potential as fiber reinforcement. With this in mind, this study's objective is to assess the workability, compressive strength, and tensile strength properties of fly ash-glass waste fiber-reinforced geopolymer concrete (FRGC) with recycled steel can fibers. This study aims to determine the viability of using recycled steel can fibers to contribute to a more environmentally friendly concrete that can be used for various construction purposes.

2. Materials and Methods

2.1. Gathering of Materials

The materials used in producing the needed geopolymer concrete were ordinary Portland cement (OPC), sand, gravel, class-F fly ash, and glass waste. The researchers bought the OPC, sand, gravel, and fly ash from a local construction supplier. Meanwhile, soda-lime glass bottles were collected from local junk shops and eateries. The collected soda-lime glasses were crushed using a glass shredder from the Manila City Material Recovery Facility to produce the needed glass waste. The glass waste produced has a grain size of fine sand.

2.2. Preparation of Recycled Steel Can Fibers

Fig. 1: Recycled Steel Can Fibers

The researchers collected waste of cooking oil steel cans from restaurants located within the vicinity of Metro Manila, Philippines. The collected steel cans' waste was washed and dried. Then, the cans were transported to a local construction company named Fundamentum Construction for the cutting process. The recycled steel can fibers produced are shown in Fig. 1. A hook-end configuration was used as the fibers' interlocking mechanism. The thickness of the recycled steel can fibers was 3 mm.

2.4. Production of Fly Ash-Glass Waste Fiber-Reinforced Geopolymer Concrete

The researchers followed ASTM C31 in producing concrete test cylinders. 30% by weight of cement was replaced by by fly ash, while 30% by weight of coarse aggregates was replaced by glass waste. Recycled steel can fibers were then added added to the geopolymer concrete mix, with fiber content percentages of 0.0%, 1.0%, 2.0%, 3.0%, 4.0%, and 5.0% of the the weight of the cement, therefore producing six (6) treatments. The materials were first mixed until homogenous before adding water at a 0.6 water-cement ratio. After that, the FRGC mix was poured into PVC cylindrical molds of 100 mm in diameter and 200 mm in height. The cylindrical molds were fabricated by the researchers following ASTM C470. The molded FRGCs were left to dry and cure for 28 days. A total of 36 FRGC samples were produced for the study, providing three (3) samples for compressive strength test and another three (3) samples for tensile strength test per treatment.

2.5. Workability Test, Compressive Strength Test, and Tensile Strength Test

Before the FRGC mixes were poured in concrete cylinder molds, workability testing or concrete slump test of the produced FRGC treatments was done following ASTM C143. The Compressive Strength test of FRGC samples was done in accordance with ASTM C39. The analysis was done after the 28-day curing. The tensile strength of the produced FRGC samples was done using the split tensile test in accordance with ASTM C496. The researchers also used the universal testing machine for the analysis. The analysis was done after the 28-day curing.

2.6. Data Analysis

The researchers ensured that the concrete tests followed the ASTM standards during the testing and underwent precision and bias checking according to their respective ASTM standards and ASTM C670. Then, the data gathered were evaluated using cubic regression. The compressive strength test and tensile strength test were further evaluated using analysis of variance (ANOVA) followed by post-hoc tests to identify if there are significant differences between FRGC treatments. The researchers used SPSS software as the statistical analysis software for their data analysis and evaluation.

3. Results and Discussions

3.1. Workability Test

Fig. 2 shows the slump value recorded per treatment on the workability test for the fly ash-glass waste FRGC with recycled steel can fibers. Based on the data, with a water-cement ratio of 0.6, the control group (treatment 0) has a slump value of 200 mm. This indicates the concrete mix is highly workable. High workability may also be the cause of the mixture of fly ash and fine glass waste, as it is stated that these two components improve the workability of a concrete mix [5,10,11].

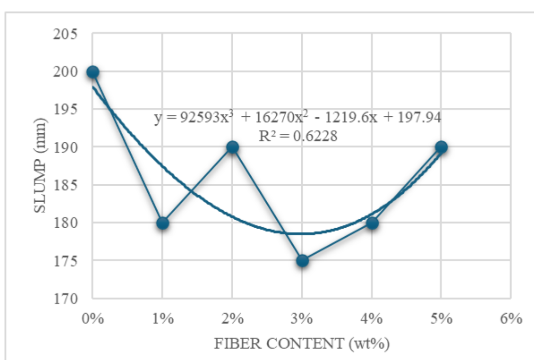

Fig. 2: Recorded slump against fiber content.

The slump value decreased and fluctuated when recycled steel can fibers were added to the concrete mix. The lowest slump value recorded was with treatment 3 (slump value of 175 mm) of the concrete mix. The produced cubic regression, which had an R-squared value of 0.6228, shows a decreasing trend until treatment 3. Afterward, an increasing trend was observed until treatment 5. All the concrete mix treatments with fiber content have a lower slump value when compared to the control group. The reduction of slump value suggests a reduction of the workability of concrete as the fiber content increases, which was observed to be a phenomenon for fiber-reinforced concrete [12,13,14,15,16,17,18]. The fluctuation slump values may have occurred due to a number of factors, such as the quantity and quality of the materials used.

3.2. Compressive Strength Test

The data gathered from the compressive strength test following ASTM C39 were first evaluated according to ASTM C670 before proceeding to data analysis. According to ASTM C39 and ASTM C670, the coefficient of variation of 3 results in a treatment shall not exceed 7.8% under laboratory conditions. All treatments passed the precision checking and were ready for data evaluation.

Table 1: Mean compressive strength at 28-day curing period

TREATMENT	FIBER CONTENT (wt%)	MEAN COMPRESSIVE STRENGTH
0	0%	33.88
1	1%	25.48
2	2%	24.01
3	3%	27.52
4	4%	27.54
5	5%	24.21

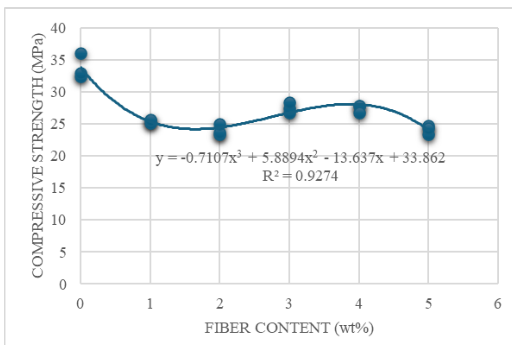

Fig. 3: Compressive strength against fiber content

Table 1 shows the mean compressive strength of the treatments at the 28-day curing period. All the treatments have exceeded the expected compressive strength design of 20 MPa. The control group (treatment 0) had a mean compressive strength of 33.88 Mpa, 69.4% higher than the expected compressive strength design.

Fig. 3 shows a cubic regression with an R-squared value of 0.9274. It can be observed that the compressive strength first decreased with the addition of fibers. The concrete mix with 2% fiber content (treatment 2) garnered the lowest mean compressive strength of 24.01 MPa. After that, the trend of the mean compressive strength increased until it reached the concrete mix with 4% fiber content (treatment 4), which has the highest compressive strength of 27.54 MPa for the concrete mix treatments with the recycled steel can fibers. After that, the trend of compressive strength decreased.

A homogeneity of variance test was conducted to see if the variances of the treatments were assumed to be equal. According to the test, the significance value or p-value is 0.027, indicating a violation of variances' homogeneity. Therefore, Welch's ANOVA is conducted alongside with one-way ANOVA. One-way ANOVA conducted in the compressive strength test data produced a significance value or p-value of 0.000, which is below the set significance level of 0.05. Moreover, Welch's ANOVA via a robust test of equality of means produced a p-value of 0.003, which is also below the significance level of 0.05. Therefore, there is a significant difference in the compressive strength between fiber content percentages of fly ash-glass waste FRGC with recycled steel can fibers.

A post-hoc Games-Howell test was conducted to determine which specific treatments differed. This type of post-hoc test hoc test was used as groups have non-homogenous variances. The significance level is set at 0.05. Based on the post-hoc hoc test, the data analysis showed that treatment 4 (4% fiber content treatment having the highest compressive strength among the concrete mix treatments with the recycled steel can fibers) is not significantly different from the control treatment treatment (treatment 0). Therefore, there is no statistically significant difference between the treatments' compressive strength.

The decrease in compressive strength may be due to the aspect ratio of the recycled steel can fibers. The fiber aspect ratio directly affects the concrete’s relative strength and toughness [13]. A higher fiber aspect ratio may have helped to lessen the compressive strength reduction or even increase the compressive strength of the fly ash-glass waste FRGC as the recycled steel can fiber content is increased [16,19]. Moreover, the orientation of the fibers and how they are dispersed in each specimen can contribute to the compressive strength results [13].

3.3. Split Tensile Strength Test

Similar to the compressive strength test, the data gathered from the split tensile test following ASTM C496 were first evaluated according to ASTM C670. According to ASTM C496 and ASTM C670, the coefficient of variation of 3 results in a treatment is suggested not to exceed 16.5%. All treatments passed the precision checking and were ready for data evaluation.

Table 2: Mean tensile strength at 28-day curing period

TREATMENT	FIBER CONTENT (wt%)	MEAN TENSILE STRENGTH
0	0%	10.13
1	1%	10.03
2	2%	6.34
3	3%	10.06
4	4%	10.39
5	5%	10.54

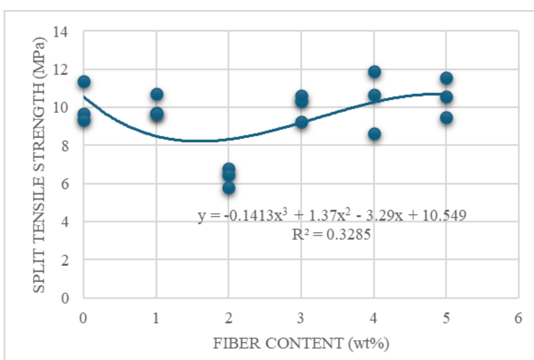

Fig. 4: Split tensile strength against fiber content

Table 2 shows the mean tensile strength of the treatments at the 28-day curing period. The control group has a mean tensile strength of 10.13 MPa. Fig. 4 shows the graph of tensile strength against fiber content, including a cubic regression with an R-squared value of 0.3285. The trend of the tensile strength decreased until it reached near the concrete mix with 2% fiber content (treatment 2), which garnered the lowest mean tensile strength of 6.34 MPa. The trend of the tensile strength then increased with a further increase in fiber content. The highest mean tensile strength of 10.54 MPa was garnered from the concrete mix having a 5% fiber content (treatment 5).

Homogeneity of variance test for the split tensile strength test data. Based on the conducted test, the significance or p-value is 0.3785, indicating that there is no violation of the homogeneity of variances. Therefore, only one-way was used. One-way ANOVA produced the significance value or p-value of 0.002, which is below the significance level 0.05. Therefore, there is a significant difference in the tensile strength between fiber content percentages of fly ash-glass waste FRGC with recycled steel can fibers.

A post-hoc Tukey HSD test was used in the split tensile strength test data, as groups have homogenous variances. Based on the post-hoc test, treatment 2 is the only treatment significantly different from the other treatments. In contrast, treatments 0, 1, 3, 4, and 5 are insignificantly different from one another. This means that despite the increase in split tensile strength recorded as the fiber content in FRGC increased, the increase was statistically insignificant.

The increase in tensile strength of fly ash-glass waste FRGC as recycled steel can fiber increases, even though it is insignificant, is aligned with the study's literature regarding fiber-reinforced concrete [16,20,21]. Similar to the compressive strength, a higher aspect ratio could have significantly improved the recycled fibers' effectiveness in increasing the tensile strength of the fly ash-glass waste FRGC [16,19]. In addition, the insignificant increase in tensile strength may be due to the glass waste decreasing the tensile strength of the concrete treatments [11]. Lastly, the orientation of the fibers and how they are dispersed in each specimen can contribute to the strength results [13].

3.4. Type of Failure

For the compressive strength test, most of the types of failures that occurred for the treatments were columnar cracking failures, followed by failures with well-formed cones at one end and vertical cracks running through caps (see Fig. 5). In addition, the researchers observed a reduction in explosive and loud failure of concrete cylinders during the test. Many of the fly ash-glass waste FRGC with recycled steel can fiber specimens exhibited a silent, ductile failure with reduced concrete spalling.

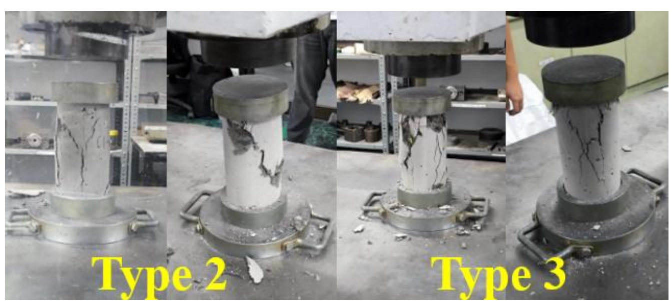

Fig. 5: Type 2 and type 3 failure in compressive test (left to right)

Meanwhile, for the split tensile strength test, the type of failure is classified into three (3) types: Type 1: visible cracks but not end-to-end, Type 2: complete separation of the fractured specimen, and Type 3: hindered fracture of the fractured specimen. A type 2 failure occurred in treatment 0. The rest of the specimens in this treatment and treatment 1 experienced a type 1 failure. Meanwhile, for the succeeding treatments (treatment 2-5), a type 3 failure was observed (see Fig. 6). The specimens that experienced a type 3 failure remained intact as they were removed from the testing machine. These phenomena observed from the type 3 failure specimens were assumed to occur because of the presence of recycled steel can fibers as reinforcement, providing the occurrence of fiber bridging to take place. Moreover, a type 3 failure also suggests a ductile failure is achieved for the concrete specimens. A ductile failure provides warning signs of impending failure through visible deformation and allows for remedial action, unlike a brittle failure that occurs suddenly without warning.

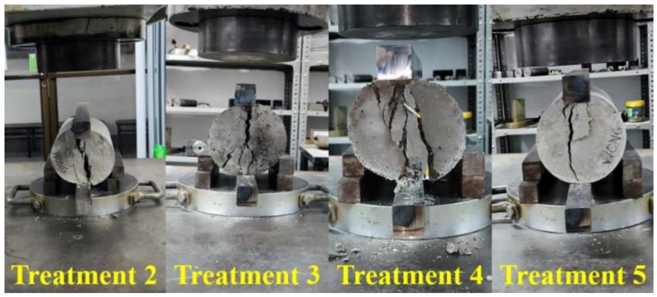

Fig. 6: Type 3 Failure in tensile test

The type of failures observed on both the compressive and split tensile tests were aligned with fiber-reinforced concrete literature and studies [12,13,14,15,16,19,20]. The presence of recycled steel can fiber in fly ash-glass waste FRGC has provided concrete with ductile performance.

4. Conclusion

This study analyzed the workability, compressive strength, and tensile strength properties of fly ash-glass waste FRGC with recycled steel can fibers. Based on the concrete tests that were conducted, the workability of FRGC decreased as recycled fibers were added. Also, the study found that there was a significant difference in the compressive and tensile properties between fiber content percentages of fly ash-glass waste FRGC. Out of the treatments conducted in this study, the fly ash-glass waste FRGC having 4% fiber steel can fiber content provided a desirable result by considering both the conducted compressive and tensile strength tests. Most importantly, the addition of fibers resulted in fiber bridging that aided the concrete samples in resisting crack propagation, which resulted in ductile failure.

Although the recycled steel can fibers did not significantly enhance the overall mechanical properties of the fly ash-glass waste FRGC, this study underscored the potential of utilizing industrial waste materials to develop more environmentally friendly and sustainable construction materials. The results support the feasibility of integrating recycled fibers into concrete production to reduce waste, minimize environmental impact, and promote sustainable practices in the construction industry. With further research and optimization, this study paves the way for the potential commercial adoption of more sustainable composite material, contributing to advancements in eco-friendly engineering solutions.

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