Optimization of Steel Fiber Reinforced- Cold-Drawn Alloy Granules as a Concrete Admixture for Improving Structural Performance

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***Abstract*: This study investigates the structural improvements obtained by introducing cold-drawn wire and steel fiber into concrete mixes, with an emphasis on their use in reinforced pavements. This study analyzes how hybrid reinforcement can overcome the constraints of standard concrete in terms of fracture resistance, ductility, and durability. Three mix designs were formulated with varying gravel replacement levels with cold-drawn alloy granules (10%, 20%, 30%), and tested for compressive strength, and flexural strength over 7-, 14-, and 28-days curing periods. Results show that a 10% CDAG substitution (M1) achieved the highest compressive strength of 17.3 MPa at 28 days, while a 20% substitution (M3) yielded the best flexural strength at 5.54 MPa. The findings suggest that a 10% replacement is optimal for compressive strength, whereas 20% benefits flexural performance. Overall, CDAG shows potential as a sustainable partial binder alternative in concrete.**

***Keywords*: Cold-drawn Alloy Granules, Steel Fiber Reinforced Concrete, Hybrid Reinforcement, Ductility Improvement, Durability, Sustainable Concrete.**

1. Introduction

Recent civil engineering studies has focused on the enhancement of concrete compounds, especially their overall structural properties. The use of cold-drawn alloy granules and steel fiber reinforcement into concrete has significant potential. This work aims to contribute to the area of civil engineering by undertaking a complete analysis and assessment of methodologies used to enhance the structural surface of cold-drawn alloy granules-steel fiber-reinforced concrete.

Steel-fiber reinforcement has stimulated the interest of academics due to its rigidity, and it is frequently employed to reinforce concrete buildings. Adding steel fibers to concrete boosts its stability and strength, improving the overall structural quality of a building. It reduces fractures, indicating durability and strength [1]. Steel fibers added to concrete allow for more control over fracture and widths. The adoption of this material has the potential to enhance the structural issues of typical reinforcements by avoiding corrosion, prolonging structure life, and minimizing fracture widths. This is important for structures that are built to withstand high weather and dynamic pressures [2].

Cold drawing is used in the wire drawing process, which entails pulling a rod or wire through a conical die that has a calibrated hole in it. This process causes the work piece's diameter to drop and its length to rise. Because of the phenomenon known as strain hardening, the products that come from this procedure are well-known for their great strength [3].

Aluminum 3004 (Al 3004) is an alloy of aluminum-manganese with moderate strength, good formability and weld ability. Aluminum 3004 (Al 3004) consists mainly of aluminum (99% minimum) plus manganese (0.8% maximum). It also contains silicon (0.6%), chromium (0.05%), iron (0.7%), copper (0.2%) and other elements in trace amounts that help improve its mechanical properties and workability. Aluminum 3004 has several uses because of its good formability and inexpensive cost, particularly in the building sector. Because of its great ductility, which enables it to be shaped into complicated forms without difficulty or loss of quality or performance attributes over time, it may be used as a concrete additive to improve structural performance [3].

Steel sheet, cold-drawn alloy granules, and other types of steel are used to make steel fibers, which are used to reinforce concrete. The most popular kind of fiber used in flooring is wire fiber. They have a range of cross sections, aspect ratios (the ratio of length to nominal diameter) from 20 to 100, and lengths up to around 60 mm. Fibers might have wavy profiles, roughened surface textures, or expanded, flattened, or hooked ends to increase their resistance to pull-out [4].

The researchers will determine how effective the steel fiber-reinforced concrete-cold-drawn alloy granules as a concrete admixture are in terms of structural performance. The researchers chose AL 3004 as admixture because it has high strength, excellent formability, and good corrosion resistance, and is used for parts that require higher strength. Soda Cans (AL 3004) will be gathered by the researchers at Materials Recovery Facility. Soda Cans (Al 3004) is commonly used to produce the body of cans, the light components. It can also be used for the processing and storage equipment of chemical products, sheet processing, and some construction tools.

A. Statement of the Problem

The research's objective is to comprehensively analyze the improvement of methods used in steel fiber reinforced with a specific emphasis on pavement that includes Cold-drawn alloy granules. The research addresses the following specific objectives:

1. To evaluate the effect of Cold-Drawn Alloy Granules (Al 3004) on mechanical properties of Steel Fiber Reinforced Concrete in pavements in terms of compressive strength test and flexural strength test
2. To identify what is the most efficient and effective ratio of Cold-Drawn Alloy Granules (Al 3004) as a concrete admixture for enhancing the performance of concrete pavement
3. To determine if steel fiber reinforced concrete-cold drawn alloy granules can be mixed with other parts of concrete, like cement, additives, and admixtures.

B. Scope and Limitation

This study focuses on the compressive and flexural strength of a beam and cylinder specimen that has alloy granules in the concrete mix. The data collection will be conducted to the testing of the said specimens that will be tested in Department of Public works and Highways- Aurora district engineering office. Applying this to the actual pavement is not within the scope of the research. The study would be done by testing the beam and the cylinder by means of Universal Testing Machine (UTM). By their strategy the researchers will be able to know if adding alloy granules to the concrete mixture is effective to use.

C. Framework of the Study

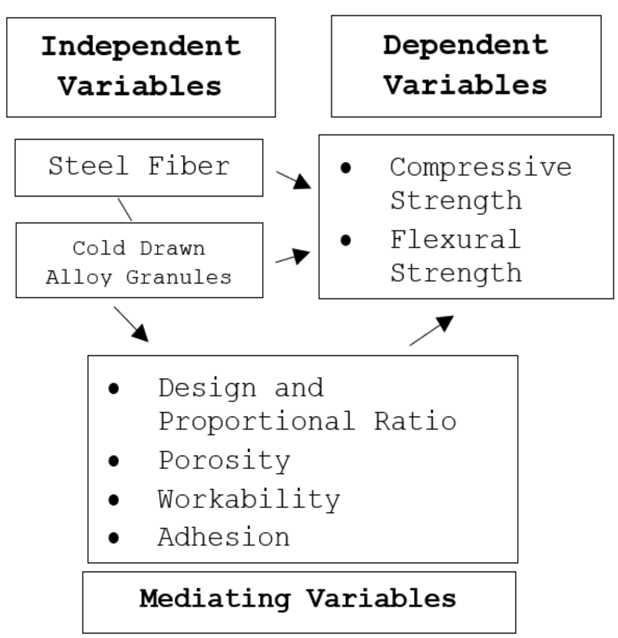

Fig. 1. Conceptual framework of the study

2. Review of Related Literature

Pavements are usually constructed using either asphalt or concrete, and their primary function is to transfer the applied loads to the underlying foundation efficiently. Concrete is characterized by its exceptionally high compressive strength and relatively low tensile strength. Consequently, it is necessary to enhance its performance under both tension and flexure conditions [5]. Utilizing steel fibers in rigid pavement significantly enhances its structural properties, including static flexural strength, impact strength, tensile strength, ductility, flexural toughness, and concrete cracking performance [5]. The most important improvement imparted by steel fibers is the ability to control crack widths and carry significant stresses after the initial cracking of the concrete [5].

A. Discussion

1) Aluminum Can Fiber as an Additive for Concrete

Nowadays waste material is being utilized in concrete as fiber to make fiber reinforcement concrete. Many researchers are studying waste materials to enhance the strength of concrete structures and identify cost-effective alternatives. The influence of soft drink aluminum can fibers has been studied in different proportions and fiber lengths to improve the performance characteristics of concrete [10]. It has similar mechanical properties to steel fiber (Memon & Akhund, 2017). Moreover, the bodies of soda cans are made of aluminum alloy (Al) 3004 [10]. Al 3004 is an aluminum-manganese alloy known for its moderate strength, excellent formability, and weld ability [11]. Alloy 3004 is primarily composed of a minimum of 99% aluminum and a maximum of 0.8% manganese [11]. The alloy also includes silicon (0.6%), chromium (0.05%), iron (0.7%), copper (0.2%), and other elements in trace amounts that help improve its mechanical properties and workability [11].

2) Effects of Fiber Content on Rigid Pavements

The primary source of load-bearing capacity in rigid pavement is the concrete slabs. This pertains to the characteristics of rigid concrete slabs, which can distribute the weight over a large surface area, hence minimizing the strain on the underlying layers [12]. Rigid concrete slabs with minimal elasticity efficiently disperse the weight of traffic across a wide surface area, thereby transferring the load to the subgrade [12]. Traditional concrete typically fails due to the deterioration of the connection between the cement paste and the aggregate [13]. Adding fiber to certain types of materials typically enhances tensile and flexural strength, while simultaneously reducing compressive strength, up to the optimal threshold [13]. The inclusion of suitable fiber can enhance the ductility of concrete while maintaining its compressive strength. The ductility of concrete will influence the progression of early cracking till the concrete ultimately fails as a result of the impact [13].

Steel fibers enhanced the ductility of the concrete by improving its stress-strain relationship [14]. The steel-fiber concrete maintains its ductility even at high temperatures and the inclusion of these fibers plays a significant role in determining the deformation pattern of the concrete, allowing for the manipulation of the fracture process of the material by utilizing steel fibers [14]. Various fibers are used in concrete to reduce cracks caused by plastic shrinkage and drying shrinkage [13]. Additionally, they decrease the permeability of concrete, resulting in a reduction of water bleeding. Certain varieties of fiber showed greater impact, abrasion, and shatter resistance in concrete [14]. Indeed, certain types of fiber can decrease the structural integrity of concrete [14].

Table 1
Challenges in using cold-drawn Alloy Granules as a concrete mixture for rigid pavement

No.	Research Gap	Citation
1	Safety of users	(Kamel, 2016)
2	Testing range	(Henderson, n.d.)
3	Create a vulnerability in the structure	(Blockley David Ian, n.d.)
4	Effect to environment	(Elliot et al., 2015)

3) Research Gap

The application of steel fibers in the building sector has been the subject of numerous investigations. The difficulties and restrictions encountered during the careful analysis of the relevant literature are detailed in this section. Following a thorough examination of the literature evaluations, the following areas show gaps in the articles:

Although steel fiber reinforced concrete is known for its strength, it does have certain drawbacks. Loose fibers at the hardened surface might be blown onto aircraft engines or tires, resulting in unsafe operation. Injury to personnel being scraped or cut by an exposed fiber while working on the concrete surface is also possible [15]. In addition, these studies have often focused on the reformed steel fiber with the largest volume friction and the best aspect ratio [15]. Steel fiber-reinforced concrete is made up of both discrete and discontinuous steel fibers and concrete mortar. It is not meant to take the role of reinforcement. Depending on the use, fibers can be employed with or without reinforcing. One of the most important steps in avoiding superfluous strength loss in concrete is the integration of fibers. For example, an area lacking these steel fibers may become weaker in that particular location if the fibers are not mixed properly [16]. Furthermore, there may be a reduction in the workability of the concrete [17]. Steel fiber reinforced concrete has a larger young's modulus, or modulus of elasticity, than regular concrete. Prior to mixing, it is important to consider many impacting aspects such as aspect ratio, fiber volume, mixing, and fiber orientation [17].

3. Methodology

The research design of this study integrates quantitative and experimental methods. Experimental Research goal is to prove that mixing cold-drawn alloy granules is effective to use in concrete mix. For an empirical study that uses statistical approaches to obtain insights that may be applied to a wider range of scenarios, the researchers used quantitative data collection methods.

A. Research Workflow

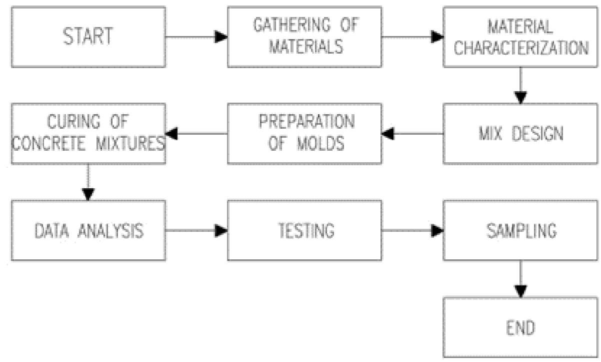

Fig. 2. Process flow diagram showing the method used to produce concrete mixtures with varied percentages of cold-drawn alloy granules

The process begins with the collection of Cold-Drawn Alloy Granules. The Cold-Drawn Alloy Granules is shredded and these materials are mix and measure all ingredients accurately using appropriate equipment, cast beam cylinder samples in molds for testing (e.g. Cylinder for Compressive Testing and Beam for Flexural Testing). Once the curing is complete, the sample undergo testing and data analysis to assess their properties and support the design of the concrete mixtures with varied percentages of Cold-Drawn Alloy Granules.

The research methodology was structured to systematically investigate these materials physical and mechanical properties for potential application in construction. The experimental design involves systematic testing to determine the optimal mix proportions and evaluate the resulting material properties, particularly its mechanical and physical properties. Statistical analysis of the collected data will ensure unbiased and reliable results, enabling the development of concrete mixtures incorporating shredded Drawn Alloy Granules as an additive.

The experimental process followed a sequential protocol:

B. For Admixtures

Step 1: Collecting and Material Characterization

1) Shredding of Cold-Drawn Alloy to Granules

Fig. 3. Shredding of cold-dram alloy

- *Sieving*: Separate sand and gravel by particle size for uniform concrete mixes. Use #40

Fig. 4. Sieving

Step 2: Preliminary Mix Design

1) Batching: Measure and Mix All Ingredients Accurately Using Appropriate Equipment.

Fig. 5. Mixing

2) Casting: Cast Beam and Cylinder Samples in Molds for Testing (E.G. Cylinder for Compressive Testing and Beam for Flexural Testing).

Step 3: Testing

1) Testing for Beam Sample

Fig. 6. Flexural testing for beam

- Flexural Strength: Test cured samples (e.g., 28 days) to ensure adequate its capacity.

2) Testing for Cylinder Sample

Fig. 7. Compressive testing for cylinder

- Compressive Strength: Test cured samples (e.g., 28 days) to ensure adequate its capacity.

3) Data Analysis

- Analyze test results and compare them against set performance targets.

C. For Adding Cold-Drawn Alloy Granules in Concrete Pavement

- *Step 1*: Mixing of cement, sand, gravel, and alloy granules.
- *Step 2*: Pour the concrete mixture into concrete mold
- *Step 3*: Create three samples for three mixtures.
- *Step 4*: Curing
  - *Mixture 1*: 7 days
  - *Mixture 2*: 7 days
  - *Mixture 3*: 7 days
  - *Mixture 1*: 14 days
  - *Mixture 2*: 14 days
  - *Mixture 3*: 14 days
  - *Mixture 1*: 28 days
  - *Mixture 2*: 28 days
  - *Mixture 3*: 28 days
- *Step 5*: After curing days, conduct compressive and flexural strength test.

D. Material Requirements

The following is the tabulated list of materials necessary in producing concrete pavement with an admixture of cold-drawn alloy granules.

Table 2

The materials that will be used to produce the product

No.	Materials	Specification
1	Cold- Drawn Alloy Granules	Thin Cans (AL) 3004, is widely used in construction due to its inherent qualities of low weight and resistance to corrosion. Passing through Sieve no. 16
2	Cement	Portland Cement AASHTO M-85, Type I, is considered a general, all-purpose cement and is used when the special properties of the other cement types are not required. Passing through Sieve no. 200.
3	Fine Aggregates	Natural sand, with similar characteristics, or combinations thereof, having hard, strong and durable particles. It shall be washed thoroughly with fresh water and shall be made in order to remove the impurities and other chemical constituents that might have an adverse effect on the performance of the concrete pavement. Passing through sieve no. 40.
4	Water	Potable Water (wash water)
5	Gravel	Along with sand, is used for the manufacture of concrete, as well as for mixing with asphalt as part of road construction. ¾ inch, passing through Sieve no. 4.

E. Mix Design

It is important that specimens are prepared and cured in accordance with ASTM standards. Low strength test results due to non-standard processes may cause unnecessary concern, cost, and delay in the project (Gacutan 2015). The strength data could also be used to determine when the structure is ready for service, as well as to evaluate the effectiveness of curing and protecting concrete in structures. Using ASTM C192/C192M-02: Standard and Practice for Making and Curing Test Specimens in the Laboratory and ACI 211.1-91: Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete, the researcher arrived at the following calculation:

Volume of Cylinder (V) = $\pi r^2 h$
= (3.1416) (3) ² (12)
= 339.2928 in³ = $\underline{0.007272\ \text{yd}^3}$

Volume of Beam (V) = L x W x h
= (20)(6)(6) = 720 in³ = $\underline{0.0154321\ \text{yd}^3}$

1) Cylinder Sample:

- Mixture 1
  - *cement* : 1.882 kg
  - *Gravel* : 5.5602 kg
  - *sand* : 4.217 kg
  - *water* : 0.001039 m³
  - *Cold-Drawn Alloy Granules* : 0.6178kg (10 % gravel replacement)
- Mixture 2
  - *cement* : 1.882 kg
  - *Gravel* : 4.9424 kg
  - *sand* : 4.217 kg
  - *water* : 0.001039 m³
  - *Cold-Drawn Alloy Granules* : 1.2356 kg (20 % gravel replacement)
- Mixture 3
  - *cement* : 1.882 kg
  - *Gravel* : 4.3246 kg
  - *sand* : 4.217 kg
  - *water* : 0.001039 m³
  - *Cold-Drawn Alloy Granules* : 1.8534 kg (30 % gravel replacement)

Table 3
Mix design

Materials	Mixture 1	Mixture 2	Mixture 3
Cement (kg)	1.882	1.882	1.882
Gravel (kg)	5.5602	4.9424	4.3246
Sand (kg)	4.217 kg	4.217 kg	4.217
Water (m³)	0.001039	0.001039	0.001039
Cold-Drawn Alloy Granules (g)	0.6178kg	1.2356	1.8534

2) Beam Sample:

- Mixture 1
  - *cement* : 3.994 kg
  - *Gravel* : 11.8008 kg
  - *sand* : 8.948 kg
  - *water*: 0.0022050 m³
  - *Cold-Drawn Alloy Granules*: 1.3112 kg (10 % gravel replacement)
- Mixture 2
  - *cement*: 3.994 kg
  - *Gravel*: 10.4896 kg
  - *sand:* 8.948 kg
  - *water*: 0.0022050 m³
  - *Cold-Drawn Alloy Granules*: 2.6224 kg (20 % gravel replacement)
- Mixture 3
  - *cement*: 3.994 kg
  - *Gravel*: 9.1784 kg
  - *sand*: 8.948 kg
  - *water*: 0.0022050 m³
  - *Cold-Drawn Alloy Granules*: 3.9336 kg (30 % gravel replacement)

Table 4
Mix design

Materials	Mixture 1	Mixture 2	Mixture 3
Cement (kg)	3.994	3.994	3.994
Gravel (kg)	11.8008	10.4896	9.1784
Sand (kg)	8.948	8.948	8.948
Water (m³)	0.0022050	0.0022050	0.0022050
Cold-Drawn Alloy Granules (g)	1.3112	2.6224	3.9336

F. Specimen Details

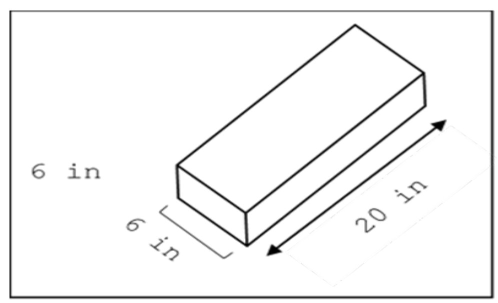

Fig. 8. Dimension of beam specimen sample

To determine the compressive and flexural behavior, beam specimens with dimensions of 30 in × 6 in × 6 in will undergo testing. The composite is subjected to bending testing, in order to examine its flexural strength and behavior.

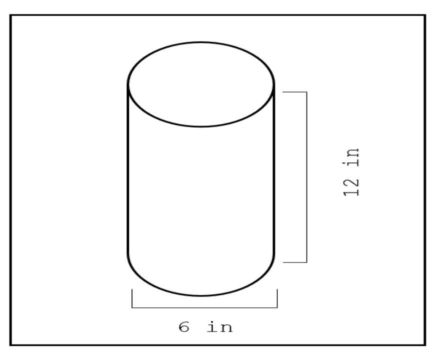

Fig. 9. Dimension of cylinder specimen sample

1) Specimen Composition

The concrete block with a length of 30 in, width of 6 in height of 6 in is made out of cement, sand, water, gravel and alloy granules.

2) Specimen Discussion

To determine the compressive and flexural strength, cylinder specimens with dimensions of 6 in × 12 in will undergo testing.

3) Specimen Composition

The cylinder with a dimension of 6 in, and a height of 12 in is made out of cement, sand, water, gravel and alloy granules.

G. Laboratory/Experiment/Field Experiment

1. Compressive Strength Test
2. Flexural Strength Test

Concrete performance is primarily evaluated using compressive and flexural strength tests. Concrete specimens are crushed after 7 and 28 days to determine their compressive strength, in accordance with AASHTO T22 and ASTM C39 standards that assess the load-bearing capacity of the concrete. Flexural strength is measured using ASTM D6272 with four-point loading over a 300 mm span. One beam per concrete mix is tested, and strength is calculated based on the failure load, span, width, and depth of the specimen (100 mm × 100 mm). A strain gauge is placed in the center of each specimen, and the crack width is measured in one sample per mix. These tests aid in determining key performance indicators such as the flexural load-deflection curve, strain behavior, and crack formation, thereby providing a comprehensive picture of the concrete's structural performance.

H. Description of Research Instrument Used

In this study, the researcher will be using a graph. The graph is all about the data that will be gathered during the testing of the flexural strength of the specimens. The type of graph that the researchers will be using is line graph, to present the data in simple way. The researcher will also use excel for data collection.

4. Results and Discussion

This chapter presents the research Compressive and Flexural Test Results. The study data must be analyzed to test the hypothesis and answer the research questions. The researchers' collected results shows that Compressive Strength replacing 10% of the binder with Cold-Drawn Alloy Granules resulted in better strength development than both the higher replacement levels and the control mix. While Flexural Strength, using Cold-Drawn Alloy Granules in place of 20% of the binder produced superior strength development compared to both the control mix and greater replacement levels.

Concrete mixtures with varied percentages of Cold-Drawn Alloy Granules had their compressive strength evaluated at 7, 14, and 28 days. The result for different type of specimen samples is shown in figure 7.

Specimen M1, which had the lowest replacement level (10% Cold-Drawn Alloy Granules) achieved the highest strength at 28 days, reaching 17.3 MPa, indicating its better performance in terms of strength development. It also demonstrated steady strength growth at each interval, increasing from 7.9 MPa at 7 days to 10.3 MPa at 14 days, before peaking at 28 days. Specimen M3 (20% Cold-Drawn Alloy Granules replacement) also performed well, starting at 7.4 MPa at 7 days and improving to 10.4 MPa at 14 days, then achieving 14.2 MPa at 28 days. This consistent increase reflects a stable hydration process and a well-balanced mix design. In contrast, specimen M2 (30% Cold-Drawn Alloy Granules replacement) experienced a temporary decline in strength at the 14-day mark, dropping from 8 MPa at 7 days to 6.5 MPa. However, it recovered significantly by 28 days, achieving a final compressive strength of around 14.2 MPa.

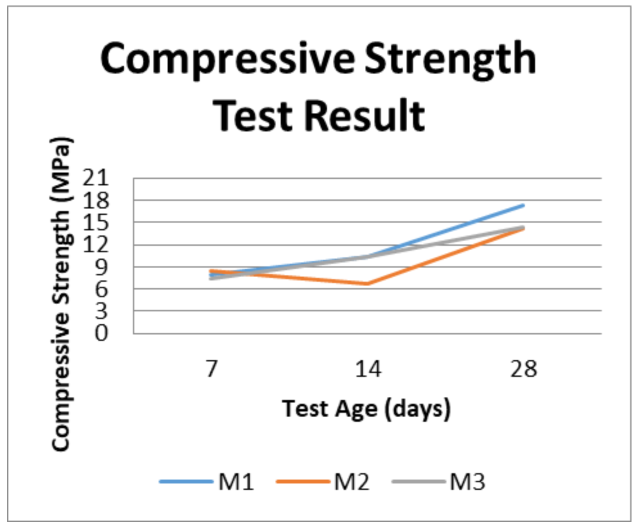

Fig. 10. Compressive strength test result

Overall, M1 proved to be the most effective mixture, achieving a balance between strength and sustainability. In contrast, M2 and M3 did not demonstrate sufficient structural reliability. As illustrated in the graph, M1 consistently achieved the highest compressive strength at both 7 and 28 days. M2 and M3, on the other hand, had lower compressive strengths compare to M1. These findings indicate that Cold-Drawn Alloy Granules can enhance concrete performance when used in proper proportions. Specifically, replacing 10% of the binder with Cold-Drawn Alloy Granules resulted in better strength development than both the higher replacement levels and the control mix. The outcomes highlight the importance of appropriate mix design and adequate curing time in optimizing compressive strength.

The ability of concrete to resist bending and cracking is measured in large part by its flexural strength. The flexural strength of concrete usually increases as it cures. The flexural strength of concrete mixtures containing different proportions of Cold-Drawn Alloy Granules is evaluated at 7, 14, and 28 days. The 28-day strength is frequently used as a standard for design and quality assurance. The result for different type of specimen samples is shown in figure 8.

With the lowest replacement level (10% Cold-Drawn Alloy Granules), specimen M1 demonstrated superior strength development performance by achieving the highest strength at 28 days, 5.47 MPa. From 4.18 MPa at 7 days to decreasing 3.88 MPa at 14 days, and finally reaching its peak at 28 days, it likewise showed inconsistent strength growth at each interval.Specimen M3 (20% replacement of Cold-Drawn Alloy Granules) demonstrated good performance, beginning at 4.18 MPa at 7 days, decreasing to 3.07 MPa at 14 days, and reaching 4.87 MPa at 28 days. This progressive increase is indicative of a well-balanced mix design. Furthermore, specimen M2 (30% replacement of Cold-Drawn Alloy Granules) temporarily lost strength at day 14, falling from 5.13 MPa at 7 days to 4.01 MPa for 14 days. But after 28 days, it had recovered considerably, reaching a final compressive strength of about 5.54 MPa.

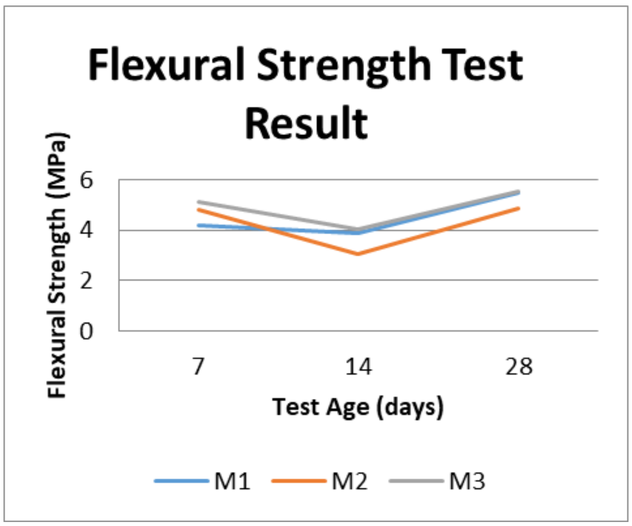

Fig. 11. Flexural strength test result

Overall, M3 was the best combination, striking a balance between sustainability and strength. However, neither M1 nor M2 showed enough structural reliability. The graph shows that M3 continuously had the maximum flexural strength at 7 and 28 days. In contrast, M3 exhibited higher flexural strength than M1 and M2. These results show that, when applied in the right amounts, Cold-Drawn Alloy Granules can improve the performance of concrete. In particular, using Cold-Drawn Alloy Granules in place of 20% of the binder produced superior strength development compared to both the control mix and greater replacement levels. The results emphasize how crucial proper mix design and sufficient curing time are to maximizing flexural strength.

5. Conclusion and Recommendation

This study examined the impact on compressive and flexural strength of substituting Cold-Drawn Alloy Granules (CDAG) for some of the binder in concrete. The experimental findings showed that the percentage of CDAG used in concrete affected its performance. The specimen with a 10% CDAG substitution (M1) had the best compressive strength, peaking at 17.3 MPa after 28 days and exhibiting the greatest strength development over all curing ages. On the other hand, the 20% CDAG replacement (M3) performed the best in terms of flexural strength, reaching the maximum of 5.54 MPa at 28 days.

The findings show that a 10% replacement is most helpful for compressive strength, but a 20% replacement improves flexural strength. The study demonstrates that CDAG may be an efficient partial binder alternative in concrete, improving structural performance and sustainability when applied in the proper quantities.

- *Explore Surface Wear Resistance*: Conduct abrasion and impact resistance tests to determine the suitability of CDAG-reinforced concrete for high-traffic pavement applications.
- *Study Environmental Effects*: Examine the effects of environmental exposure on the mechanical and chemical stability of CDAG in concrete, including moisture, temperature changes, and corrosive agents.
- *Assess Workability and Mixing Efficiency*: Analyze how the amount of CDAG in fresh concrete affects its workability, mixing consistency, and possible segregation problems.
- *Evaluate Structural Applications Beyond Pavement*: To investigate greater application potential, test CDAG concrete mixes for additional structural elements such as slabs, columns, or precast components.
- *Compare with Other Recycled Materials*: Compare CDAG's performance, cost, and sustainability against those of other recycled or industrial waste admixtures.
- *Quantify Life Cycle Environmental Impact*: To measure the environmental advantages or trade-offs of employing CDAG in the manufacture of concrete, do a life cycle assessment (LCA).

6. Acknowledgement

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References

[1] Alberti, M. G., Picazo, Á., Gálvez, J. C., & Enfedaque, A. (2020). New methodological approach towards a complete characterization of structural fiber reinforced concrete by means of mechanical testing procedures. Applied Sciences (Switzerland), 10(14). doi: 10.3390/app10144811

[2] Dhilipkumar, R., Prakash, S., Prasanna Adithyan, R., & Sriram, A. (n.d.). Experimental Investigation on Steel Fiber Reinforced Concrete. International Journal of Innovative Research in Engineering, 4(3), 215–218. doi: 10.59256/ijire.2023040376

[3] Ionițoaiei, P., & Rotaru, A. (2023). Studies on heavy duty pavements reinforced with steel fibers for port infrastructures. IOP Conference Series: Materials Science and Engineering, 1283(1), 012006. doi: 10.1088/1757-899x/1283/1/012006

[4] Nogales, A., & de la Fuente, A. (2021). Numerical-aided flexural-based design of fibre reinforced concrete column-supported flat slabs. Engineering Structures, 232, 111745. doi: 10.1016/J.ENGSTRUCT.2020.111745

[5] Panzera, T. H., Christoforo, A. L., & Ribeiro Borges, P. H. (2013). High performance fibre-reinforced concrete (FRC) for civil engineering applications. Advanced Fibre-Reinforced Polymer (FRP) Composites for Structural Applications, 552–581. doi: 10.1533/9780857098641.4.552

[6] Patel, M., Shakil, S., Chande, L., & Professor, A. (2018). Study and Strength Analysis of Fiber Reinforced Concrete. In IJSRD-International Journal for Scientific Research & Development| (Vol. 5). Retrieved from www.ijsrd.com

[7] Soutsos, M. N., Le, T. T., & Lampropoulos, A. P. (2012). Flexural performance of fibre reinforced concrete made with steel and synthetic fibres. Construction and Building Materials, 36, 704–710. doi: 10.1016/J.CONBUILDMAT.2012.06.042

[8] Tiberti, G., Minelli, F., & Plizzari, G. (2015). Cracking behavior in reinforced concrete members with steel fibers: A comprehensive experimental study. Cement and Concrete Research, 68, 24–34. doi: 10.1016/J.CEMCONRES.2014.10.011

[9] Wtaife, S., Eissa, T., Alsabbagh, A., & Alshammari, E. (2018). Analysis of flexural capacity of fiber reinforced concrete pavements. International Journal of Technology and Engineering Studies, 4(6). https://doi.org/10.20469/ijtes.4.10001-6

[10] Vishwakarma, R. J., & Ingle, R. (2018). Effect of panel size and radius of relative stiffness on critical stresses in concrete pavement. Arabian Journal for Science and Engineering, 43(10), 5677–5687. https://doi.org/10.1007/s13369-018-3308-x

[11] Soroushian, P. (2019.). FIBER-TYPE EFFECTS ON THE PERFORMANCE OF STEEL FIBER REINFORCED CONCRETE. https://trid.trb.org/view/353874

[12] Straffelini, G. (2023). Wire drawing. In Elsevier eBooks (pp. 365–376). https://doi.org/10.1016/b978-0-323-99203-9.00004-1

[13] Taher, S. A., Alyousify, S., & Hassan, H. J. A. (2020). Comparative study of using flexible and rigid pavements for roads: A review study. Journal of Duhok University, 23(2), 222-234.

[14] Otti, V. I., Nwolun, C., and Ezechukwu, M. D. K. (2016). Rigid pavement as an alternative to flexible pavement failure in ogbaru swampy area. Civil and environmental research (IISTE), 8(3), 2225-0514.

[15] Yazdani, G. (2018). Effect of Nanopolymer Modified Binder on Hot Mix Asphalt. Thesis, University of North Dakota, USA.\

[16] Mohod, M. V., & Kadam, K. N. (2016). A comparative study on rigid and flexible pavement: A review. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 13(3), 84-88.

[17] Wimsatt, A. J., Chang-Albitres, C. M., Krugler, P. E., Scullion, T., Freeman, T. J., and Valdovinos, M. B. (2009). Considerations for rigid vs. flexible pavement designs when allowed as alternate bids: technical report (No. FHWA/TX-09/0-6085-1)

[18] Scheving, A. G. (2011). Life Cycle Cost Analysis of Asphalt and Concrete Pavements. Doctoral dissertation, Reykjavík University, Iceland.

[19] Kumutha R, Vijai K, "Effect of Steel Fibers on the Properties of Concrete" Journal of Reinforced Plastics and Composites, Vol 29, Issue 4, pp. 531–538,2009.

[20] Jhatial, A. A., Sohu, S., Bhatti, N., Lakhiar, M. T., & Oad, R. (2018). Effect of steel fibres on the compressive and flexural strength of concrete. International Journal of Advanced and Applied Sciences, 5(10), 16–21. https://doi.org/10.21833/ijaas.2018.10.003

[21] Su, N., & Fan, X. (2021). Experimental study on flexural toughness of Steel-Polyvinyl Alcohol hybrid fiber reinforced concrete. IOP Conference Series: Earth and Environmental Science, 719(2), 022080. https://doi.org/10.1088/1755-1315/719/2/022080

[22] E. A. Latifa, R. Aguswari, and P. H. Wardoyo,(2013). "Performance of steel fiber concrete as rigid pavement," Advanced Materials Research, vol. 723, pp. 452–458, Aug. 2013,

[23] Salman, B. A., & Hassan, R. F. (2023). Comparison between the effects of straight and hook steel fibers on fresh and hardened characteristics of concrete. E3S Web of Conferences, 427, 02011. https://doi.org/10.1051/e3sconf/202342702011

[24] M. Heeralal, R. P. Kumar, and Y. V. K. S. Rao, "Flexural fatigue characteristics of steel fiber reinforced recycled aggregate concrete (SFRRAC)," Facta Universitatis, vol. 7, no. 1, pp. 19–33, Jan. 2009, doi: 10.2298/fuace0901019h.

[25] H. A. Lie, A. Antonius, and A. W. Okiyarta, "Experimental Study of Steel-fiber Reinforced Concrete Beams with Confinement," Procedia Engineering, vol. 125, pp. 1030–1035, Jan. 2015, doi: 10.1016/j.proeng.2015.11.158.

[26] M. Ahmadi, S. Farzin, A. Hassani, and M. Motamedi, "Mechanical properties of the concrete containing recycled fibers and aggregates," Construction and Building Materials, vol. 144, pp. 392–398, Jul. 2017, doi: 10.1016/j.conbuildmat.2017.03.215.

[27] I. Hussain, B. Ali, T. Akhtar, M. S. Jameel, and S. S. Raza, "Comparison of mechanical properties of concrete and design thickness of pavement with different types of fiber-reinforcements (steel, glass, and polypropylene)," Case Studies in Construction Materials, vol. 13, p. e00429, Dec. 2020, doi: 10.1016/j.cscm. 2020.e00429.

[28] H. Farhan, A. Dawson, and N. Thom, "Damage propagation rate and mechanical properties of recycled steel fiber-reinforced and cement-bound granular materials used in pavement structure," Construction and Building Materials, vol. 172, pp. 112–124, May 2018, doi: 10.1016/j.conbuildmat.2018.03.239.

[29] Błaszczyński, T., & Przybylska-Fałek, M. (2015). Steel Fibre Reinforced Concrete as a Structural Material. Procedia Engineering, 122, 282–289. https://doi.org/10.1016/j.proeng.2015.10.037

[30] Saidani, M., Saraireh, D., & Gerges, M. (2016). The behavior of different types of fiber-reinforced concrete without admixture. Engineering Structures, 113, 328–334. https://doi.org/10.1016/j.engstruct.2016.01.041