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EXPERIMENTAL APPROACH FOR DEVELOPMENT OF SUSTAINABLE HYBRID GRADED FIBER REINFORCED CONCRETE BY CONSUMING LATHE WASTE STEEL FIBERS WITH GLASS FIBERS FOR ENHANCED MECHANICAL PROPERTIES

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Abstract

Local workshops generate large quantities of industrial lathe waste steel fibers, which the steel manufacturing industries find difficult to recycle because of their sharp edges. The utilization of lathe waste steel fibers as fiber reinforcement is sustainable in concrete because these fibers have the same properties as steel fibers. Furthermore, using combinations of ductile and elastic fibers improves strain capacity and resistance to pre- and post-cracking. This research employs hybrid fiber reinforcement technology, utilizing industrial lathe waste steel fibers and glass fibers in varying proportions, to bridge the micro and macro cracks in concrete specimens. This research was done to examine the physical (workability) and mechanical properties (compressive and flexural strength) of hybrid fiber-reinforced concrete. In this research different mixtures of hybrid fiber-reinforced concrete were cast and designated as M0, M1, M2, M3, M4, M5, and M6. The mixtures included lathe waste *steel fibers at 0%, 0.50%, 1%, 1.5%, 2%, 2.5%, and 3%, and glass fibers at 0%, 0.15%, 0.25%, 0.45%, 0.60%, 0.75%, and 0.90%, respectively. The ASTM-standardised protocols were followed for all laboratory testing. The physical property results showed a decrease in the workability of concrete mixes as the percentage of lathe waste steel and glass fiber increased. This suggests that a higher percentage of lathe waste steel and glass fibers leads to a lower slump value. Consequently, the mechanical property results showed a gradual enhancement in the compressive and flexural strengths of hybrid fiber-reinforced concrete up to 2.5% lathe waste steel fibers and 0.75% (M5). Further incorporation causes a reduction in strength. The physical examination of fractured samples of hybrid fiber-reinforced concrete confirms that the lathe waste steel fibers yield a maximum strain before breaking down in the concrete matrix. Furthermore, lathe waste steel fibers broke rather than being pulled out, indicating a good bond with the concrete. It is recommended that up to 2.5% lathe waste steel fibers and 0.75% of glass fibers by the total weight of the concrete can be used as hybrid fiber reinforcement for optimum strength achievement.*

Keywords: Lathe waste Steel Fibers, Glass Fibers, Hybrid Fiber Reinforced Concrete, Workability, Compressive Strength, Flexural Strength, Mechanical and Physical Properties

I. Introduction

Concrete is the foundation of the construction industry in the modern era [XIX]. Making concrete strong is essential to build a durable structure that can withstand static and dynamic loads [XXIX]. Concrete structures offer better resistance to vibrations than others. Concrete is a brittle, solid composite made from water, fine and coarse aggregates, and cement in a fixed proportion. Once mixed, these elements create a fresh, liquefied mass that can take on any desired shape [XXXIII]. In solid states, concrete composites have greater strength, chemical resistance, and thermal resistance. Since these ingredients vary in quantity, the properties of concrete also vary.

Fiber reinforcement technology in concrete is not new[XIII]. Fibers have been used since ancient times. Steel fibers serve as the basis for steel fiber-reinforced concrete. Concrete can incorporate a variety of fibers, such as nylon fiber, glass fiber, coconut fiber, etc., to form fiber-reinforced concrete [XX].

A hybrid composite combines two or more fibers in a matrix to reflect each fiber's benefits. Finally, the structure will respond synergistically [II], [XXII], [IX]. A concrete composite is referred to as hybrid fiber-reinforced concrete if there is the substitution of two or more types of fibers [XXVIII]. Short fibers significantly enhance the mechanical properties of concrete as can dispersed easily in concrete [X]. This increases the concrete's modulus of elasticity. Small cracks initiate the propagation of larger cracks, thereby reducing brittleness and small crack development [XXIII]. Fibers debonding, or pullout from concrete, is difficult due to strong bonding, especially steel fibers. This gives hybrid fiber-reinforced concrete fracture resistance and toughness under static, dynamic, and cyclic loading [XI].

Concrete is a popular construction composite. It has weak tensile strength, which is known since the early 18th century [XXXII]. Due to weak tensile strength and brittleness, tensile failure occurs unexpectedly. Concrete is weak in tension and brittle when subjected to tension and flexure loads, causing micro and macro cracks [XIV].

The presence of fibers with higher strength and durability in hybrid reinforcement concrete is significant [XXX]. It is an undeniable fact that hybrid fiber-reinforced concrete is used in civil engineering [XXIV]. Thus, this study investigates hybrid fiber reinforcement with a concrete composite [XXXV]. HFRC is made from a mix of fibers with different material properties that bond together when added to concrete to enhance their mechanical properties [VII]. To improve concrete properties, hybrid fiber reinforced concrete uses two or more fibers in a matrix [XXVI], [XXXI].

Lathe waste steel fibers, available for free, enhance concrete's strength, toughness, and crack resistance, making them a cost-effective and sustainable alternative to commercial fibers. Their use reduces material costs while improving performance and durability in large-scale construction projects.

II. Literature Review

To ensure that freshly obtained concrete is both workable and capable of withstanding loads and weather conditions once it has hardened, it is important to mix the constituents appropriately [XVI]. Concrete requires fiber reinforcement from fiber materials with a higher tensile strength because it is strong in compression but weak in tension [IV].

The research indicates that the incorporation of steel fiber into concrete enhances the strength and durability of the concrete composite [XXXIV], [XXVII], [XII]. Researchers are conducting research to address the issue of concrete's tensile strength. Additionally, researchers are attempting to develop high-performance concretes by incorporating different fibers and admixtures into concrete in varying proportions [XVIII], [XXV]. Researchers have conducted studies to enhance the strength of concrete. Researchers have discovered that incorporating fibers into concrete improves a variety of properties, including cracking resistance, impact resistance, wear resistance, ductility, and fatigue resistance, among other strength properties [V], [III].

The most commonly used fibers and waste materials in civil engineering applications include lathe waste steel, polypropylene, and glass fibers [VI].

Researchers have discovered that concrete reinforced with steel and glass fibers possesses flexural properties that are superior to those of plain concrete [XV]. The use of glass-reinforced fiber in concrete can increase its overall strength as well as other mechanical properties [VIII].

The lathe industry produces lathe waste steel scraps, which are produced by the lathe machines during the process of shaping various machine parts [I]. These wastes are then deposited into the soil, leading to land pollution, which in turn contributes to the creation of an unhealthy environment. Also, the sharp edges make it difficult for the steel industry to recycle. The concrete construction industry can utilize these steel scraps [XXI]. In addition to fostering sustainable progress and providing environmental compensation, the use of lathe waste steel fibers as a means of recycling fibers with concrete is likely to occur. Concrete reinforced with lathe waste steel fibers produces materials known as Lathe Waste Steel Fiber-Reinforced Concrete (LWSFRC) [XVII].

III. Research Methodology

This study examined the feasibility of hybrid fiber-reinforced concrete by consuming lathe waste steel and glass fiber in various proportions, testing workability, compressive strength, and flexural strength. These parameters were determined by adding 0%, 0.5%, 1%, 1.5%, 2%, 2.5%, and 3% lathe waste steel fibers and 0, 0.15%, 0.3%, 0.45%, 0.60%, 0.75%, and 0.90% glass fibers to concrete. Each mixture was labeled M0, M1, M2, M3, M4, M5, and M6. All tests followed guidelines fixed by ASTM. The materials and quantities used in the preparation of the concrete mix include cement, coarse aggregate, final aggregate, lathe waste steel, and glass fibers.

Lathe waste steel fibers were obtained from locally available lathe machines lathing the cast iron steel pipes. The lathe waste fibers were of different ranges from 1 to 3 inches in size. While glass fibers were ordered from the National Supplier Company (NSC) Karachi, Sindh, Pakistan. Each glass fiber was 1.5 inches in size.

Fig. 1. Lathe waste steel fibers

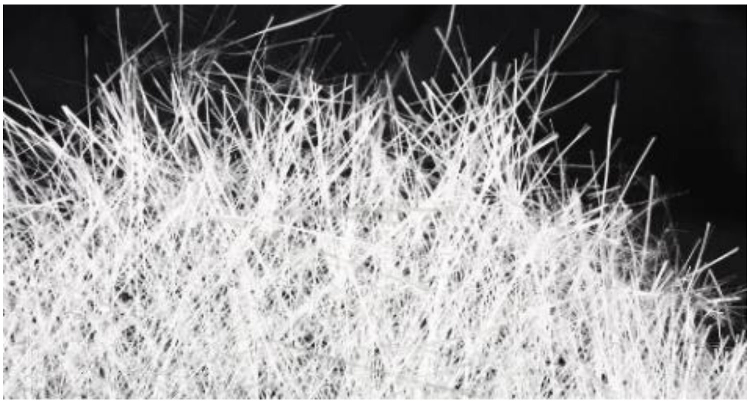

Fig. 2. Glass fibers

Concrete mixtures were prepared for physical and mechanical properties with 0%, 0.5%, 1%, 1.5%, 2%, 2.5%, and 3% of lathe waste steel fibers and 0%, 0.15, 0.25, 0.45%, 0.60%, 0.75%, and 0.90% glass fibers to form hybrid fiber reinforced concrete. Table 1 Exibits concrete sample numbers.

Table 1: Number of concrete cylindrical samples for compressive and Flexure strength

Concrete Mix	Lathe waste added (%)	Glass fibers (%)	Compressive strength	Flexural strength
			28 Days	28 Days
M0	0	0	3	3
M1	0.5	0.15	3	3
M2	1	0.30	3	3
M3	1.5	0.45	3	3
M4	2	0.60	3	3
M5	2.5	0.75	3	3
M6	3	0.90	3	3

Tables 2 and 3 list the batch quantities for control and hybrid fiber-reinforced concrete mixes for three cylindrical and flexural specimens for compressive and flexural strength.

Table 2: Quantities of ingredients for hybrid fiber-reinforced concrete mix for three companion concrete cylinders for compressive strength

Mix Designation	Cement (kg)	Sand (kg)	Coarse aggregate (kg)	Lathe Steel waste Fibers		Glass Fibers		Water (Liter)
				%	Kg	%	Kg	
M0	8	16	24	0	0	0	0	4
M1	8	16	24	0.5	0.24	0.15	0.072	4
M2	8	16	24	1	0.48	0.30	0.144	4
M3	8	16	24	1.5	0.72	0.45	0.216	4
M4	8	16	24	2	0.96	0.60	0.288	4
M5	8	16	24	2.5	1.2	0.75	0.36	4
M6	8	16	24	3	1.4	0.90	0.43	4

Table 3: Quantities of ingredients for hybrid fiber-reinforced concrete mix for three companion concrete beams for flexural strength

Mix Designation	Cement (kg)	Sand (kg)	Coarse aggregate (kg)	Lathe Steel waste Fibers		Glass Fibers		Water (Liter)
				%	Kg	%	Kg	
M0	10.66	21.33	32	0	0	0	0	5.5
M1	10.66	21.33	32	0.5	0.32	0.15	0.09	5.5
M2	10.66	21.33	32	1	0.64	0.30	0.19	5.5
M3	10.66	21.33	32	1.5	0.96	0.45	0.28	5.5
M4	10.66	21.33	32	2	1.28	0.60	0.38	5.5
M5	10.66	21.33	32	2.5	1.60	0.75	0.48	5.5
M6	10.66	21.33	32	3	1.92	0.90	0.57	5.5

Fig. 3. Materials for hybrid fiber reinforced concrete mixing

Fig. 4. Concrete Cylindrical Specimen for Compression Test

Fig. 5. Concrete Beam Specimen for Flexure Test

Physical Property of Hybrid Fiber Reinforced Concrete

Workability Tests of Fresh Concrete

The ASTM C 143/C 143M-05a test procedure was adopted for the workability test. The mold interior was cleaned and dampened with a cloth before testing. The slump height was measured immediately for evaluation of the physical property of hybrid fiber-reinforced concrete.

Fig. 6. Slump Test for fresh concrete

Mechanical Properties of Hybrid Fiber Reinforced Concrete

Compressive strength Test ASTM C-39/39M

Concrete cylindrical samples were tested after a post-curing age of 28 days. Before testing, the height and diameter of cylindrical concrete samples were measured to ensure the standard size of the specimen. Cleaning the universal testing machine's upper and lower plates was done. Concrete cylindrical samples were placed one by one in the universal testing machine. The load was applied till the concrete specimen failed.

Fig. 7. Compression Test

Flexural strength test (ASTM C-293/C293M-10)

The purpose of measuring the fractured side after testing was to determine the dimensions of the specimen section, which was then used to calculate the modulus of rupture in the form of flexural strength. The specimens were tested as per ASTM Standards. The load was applied on the central point until failure known as single point loading or mid point loading method.

Calculate the modulus of rupture as follows:

$$R = \frac{3PL}{2bd^2} \text{ (ASTM C-293/C293M-10)} \qquad (1)$$

Where

R = modulus of rupture, MPa [psi]

P = maximum applied load indicated by the testing machine, N [lbf],

L = span length, mm [in.]

b = average width of specimen, at the fracture, mm [in.]

d = average depth of specimen, at the fracture, mm [in.]

Age at test

The test performed was after 28 days.

Fig. 8. Flexure Test

IV. Results and Discussions

Physical Property of Hybrid Fiber reinforced concrete (Workability Test (ASTM C143-M03)

As shown in Table 4 and Figure 9, adding lathe waste steel and glass fibers as a hybrid fiber reinforcement causes slumps of up to 73mm, 65mm, 50mm, 41mm, 37mm, 20mm, and 16mm, respectively. Control/ordinary concrete slump values come up 73 mm.

Table 4. Slump value

Mix	Lathe Waste steel Fibers %	Steel Fibers %	Slump Value (mm)	Slump Value (Inches)
M0	0	0	73	2.8
M1	0.5	0.15	65	2.5
M2	1	0.30	50	1.9
M3	1.5	0.45	41	1.6
M4	2	0.60	37	1.4
M5	2.5	0.75	20	0.7
M6	3	0.90	16	0.6

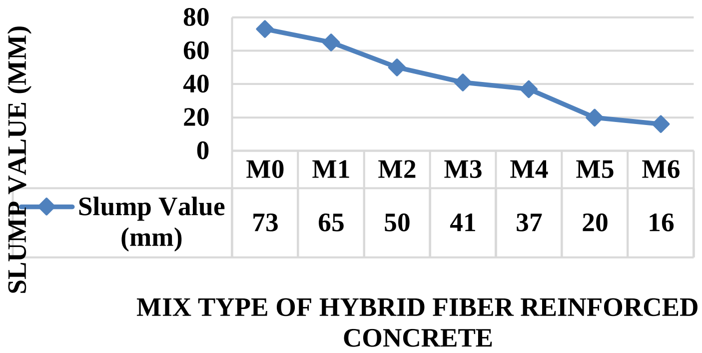

Fig. 9. Slump test result

In general, adding lathe waste steel and glass fiber decreased the workability of concrete mixes. The workability of mixes decreased with increasing percentages of lathe waste steel and glass fiber as hybrid fiber reinforcement. Fresh concrete with lathe waste steel fiber and glass fibers bonds well. Increasing the percentage of lathe waste steel and glass fibers in hybrid fiber-reinforced concrete increases bonding and decreases its slump.

Mechanical Properties of Hybrid Fiber Reinforced Concrete

Compressive strength Test ASTM C-39/39M

ASTM Standard C-39/39M compression tests were performed on control and hybrid fiber-reinforced concrete cylindrical samples with a partial addition of lathe waste steel and glass fibers. Tables 5, 6, 7, and Figures 10 and 11 respectively show the compressive test results for 28 days of curing age in a controlled environment.

Table 5: UTM Loads for Compressive test (28 days age)

Mix Designation	Lathe Waste steel Fibers %	Glass Fibers	UTM Load in KN			
			Sample 1	Sample 2	Sample 3	Average
			Load (KN)	Load (KN)	Load (KN)	
M0	0	0	366	382	351	366
M1	0.5	0.15	399	402	415	405
M2	1	0.30	433	429	455	439
M3	1.5	0.45	476	459	466	467
M4	2	0.60	479	468	480	476
M5	2.5	0.75	499	471	488	486
M6	3	0.90	351	345	324	340

Table 6: Compressive Strength calculated from load (28 days age)

Mix Designation	Lathe Waste steel Fibers %	Glass Fibers	28 Days Compressive Strength (Psi)			
			Sample 1	Sample 2	Sample 3	Average
			Strength (Psi)	Strength (Psi)	Strength (Psi)	
M0	0	0	2912	3039	2792	2914
M1	0.5	0.15	3174	3198	3301	3224
M2	1	0.30	3445	3413	3620	3492

M3	1.5	0.45	3787	3651	3707	3715
M4	2	0.60	3810	3722	3818	3782
M5	2.5	0.75	3970	3747	3882	3866
M6	3	0.90	2792	2744	2577	2705

Table 7: Compressive Strength Percent increase and decrease

Mix Designation	Lathe Waste steel Fibers %	Glass Fibers	28 Days Compressive Strength (Psi)	
			Average Strength (Psi)	Percent Increase/Decrease
M0	0	0	2914	0.00
M1	0.5	0.15	3224	10.65
M2	1	0.30	3492	19.84
M3	1.5	0.45	3715	27.49
M4	2	0.60	3782	29.78
M5	2.5	0.75	3866	32.67
M6	3	0.90	2705	-7.17

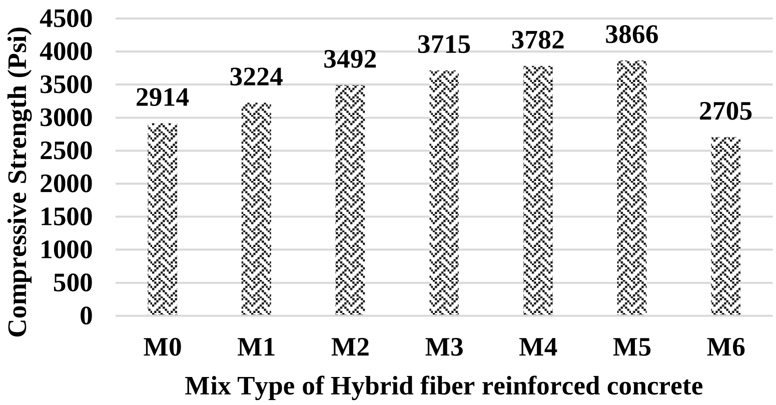

Fig. 10. Average compressive strength 28 Days

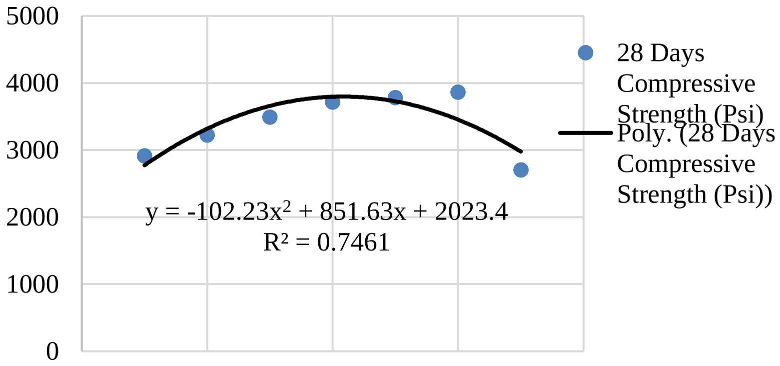

Fig. 11. Trend line of average compressive strength 28 Days

The compressive strength of hybrid fiber-reinforced concrete cylindrical samples with partial lathe waste steel and glass fibers was compared with the control specimen. Lathe waste steel and glass fibers added to concrete give an average compressive strength of 2914, 3224, 3492, 3715, 3782, 3866, and 2705 psi for three cylindrical concrete specimens. Thus, for 28 days of curing, (M5) 2.5% lathe waste steel fibers and 0.75% glass fibers yield 3866 psi, the highest compressive strength. The strength increases due to the length of the lathe waste steel fiber, which requires applied forces to break within the concrete matrix. Concrete bonds better because lathe waste breaks rather than pulls out.

Flexure Strength (28 days age)

Hybrid fiber-reinforced concrete beam samples with the incorporation of partial lathe waste steel and glass fibers were tested for flexure strength. After 28 days of curing, flexure was tested in a controlled environment. The results of the modulus of elasticity, expressed as flexural strength, are shown in Tables 8, and 9 and Figures 12, 13 respectively.

Table 8: Fracture load (P) of beam specimen (28 days age)

Mix Designation	Lathe Waste steel Fibers %	Glass Fibers %	Fracture load (P)		
			Sample 1 UTM Load (KN)	Sample 2 UTM Load (KN)	Average Fracture Load (P) KN
M0	0	0	16.5	15.3	15.9
M1	0.5	0.15	17.8	18.2	18.0
M2	1	0.30	19.1	19.4	19.3
M3	1.5	0.45	19.5	20.1	19.8
M4	2	0.60	20.8	21.9	22.1
M5	2.5	0.75	22.5	23.7	23.1
M6	3	0.90	15.2	15.8	15.5

Table 9: Flexure Strength calculated from fracture load (P) of beam specimen

Mix Designation	Lathe Waste steel Fibers %	Glass Fibers %	Flexure Strength MOR = R= R= $\frac{3PL}{2bd^2}$			
			Sample 1 MOR (Psi)	Sample 2 MOR (Psi)	Average Flexure Strength (Psi)	Percent Increase/ Decrease
M0	0	0	618	573	596	0
M1	0.5	0.15	667	682	674	13.09
M2	1	0.30	716	727	721	20.97
M3	1.5	0.45	731	753	742	24.5
M4	2	0.60	779	821	800	34.23
M5	2.5	0.75	843	888	866	45.3
M6	3	0.90	570	592	581	-2.52

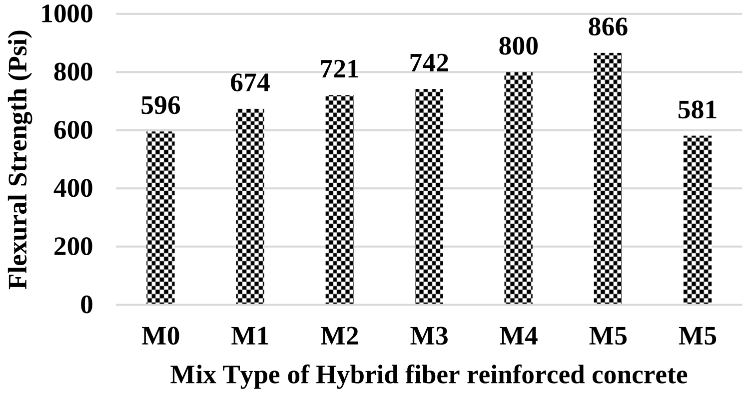

Fig. 12. Flexure strength 28 Days

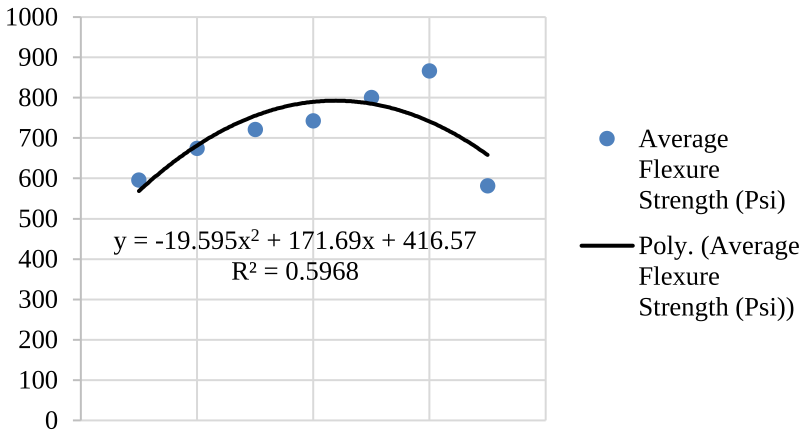

Fig. 13. Trend line of average compressive strength 28 Days

Hybrid fiber-reinforced concrete beam samples with partial lathe waste steel fiber and glass fibers were tested for flexure strength. Addition was done up to 3% lathe waste steel fibers and 0.90% glass fibers at 0.5% and 0.15% increments, respectively. Mixing lathe waste steel and glass fibers with concrete results in an average flexure strength of 596, 674, 721, 742, 800, 866, and 581 psi for two beam specimens. Flexure strength is higher than the control specimen on (M5) 2.5% lathe waste steel fibers and 0.75% glass fibers.

Comparison between flexure and compressive strength

Flexural strength is 15–20% of compressive strength, depending on mixture proportions, coarse aggregate type, size, and volume. The coefficient of variation and percentage factor are in Tables 10 and Figure 14.

Table 10: Flexure and compressive Strength coefficient of variation

Mix Designation	Lathe Waste steel Fibers %	Glass Fibers %	Average Flexure Strength (Psi)	Average Compressive Strength (Psi)	Coefficient of Variation	% Factor
M0	0	0	596	2914	0.20	20.5
M1	0.5	0.15	674	3224	0.21	20.9
M2	1	0.3	721	3492	0.21	20.6
M3	1.5	0.45	742	3715	0.20	20.0
M4	2	0.6	800	3782	0.21	21.2
M5	2.5	0.75	866	3866	0.22	22.4
M6	3	0.90	581	2705	0.21	21.5

The compressive strength study shows a similar pattern as that of flexural strength. In a concrete beam, the flexural modulus of rupture is 15% to 20% of the compressive strength.

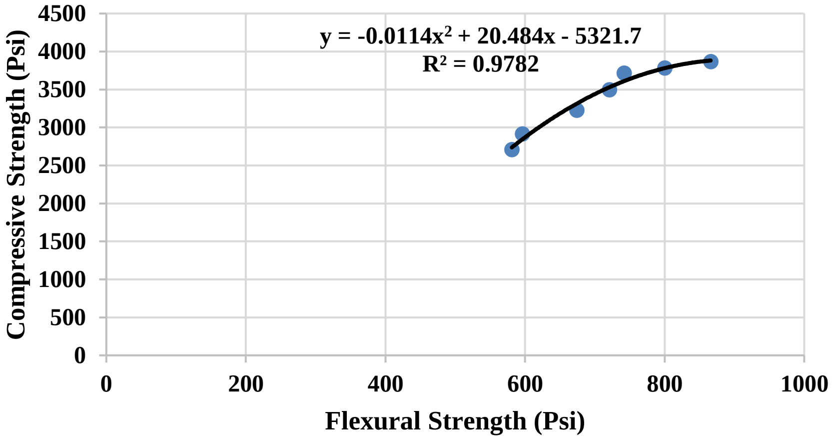

Fig. 14. Correlation between compressive and flexure strength

For hybrid fiber-reinforced concrete with lathe waste steel and glass fibers, the percent factors for modulus of rupture/flexure strength and compressive strength are 20.5%, 20.9%, 20.6%, 20%, 21.2%, 22.4%, and 21.5%. Flexure strength behaves like compressive strength, according to these findings.

V. Conclusion

It can be concluded that the workability of the mixes decreased as the percentage of lathe waste used as fiber reinforcement increased. This means that the workability decreased in fixed proportion to the amount of lathe waste steel fibers and glass fibers that were present.

The compressive and flexure strength of hybrid fiber-reinforced concrete increases with an increase in the content of lathe waste steel fiber and glass fibers up to a certain extent. The addition of 2.5% lathe waste steel fibers and 0.75 percent glass fibers results in greater compressive and flexure strength when compared to the control concrete. However, this strength decreases as the fiber content increases further. For hybrid fiber reinforcement, the optimal content is 2.5% lathe waste steel fibers and 0.75 percent glass fibers. This combination allows the mixed material to have a higher mechanical strength. The physical examination of fractured samples of hybrid fiber-reinforced concrete confirms that the lathe waste steel fibers yield a maximum strain before breaking down in the concrete matrix. Furthermore, lathe waste steel fibers broke rather than being pulled out, indicating a good bond with the concrete.

The correlation between the compressive strength and flexural strength values obtained from hybrid fiber-reinforced concrete has also been established and shows a similar pattern as that of flexural strength. In a concrete beam, the flexural modulus of rupture is 15% to 20% of the compressive strength.

VI. Recommendation

It is recommended that up to 2.5% lathe waste steel fibers and 0.75% of glass fibers by the total weight of the concrete can be used as hybrid fiber reinforcement for optimum strength achievement.

VII. Acknowledgement

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Conflict of Interest

There was no relevant conflict of interest regarding this paper.

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