Mechanical Properties of Sustainable Light Weight Steel Fiber Reinforced Concrete (SFRC) Incorporating Wood Waste as Cement Replacement

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ABSTRACT

Making concrete more sustainable is the aim of modern research, and it is why there is a significant utilization of waste materials in concrete. When it comes to sustainable concrete, it is the ultimate goal to minimize its cost and increase its applications while maintaining its core strength characteristics. Out of the different waste materials available worldwide, sawdust is considered suitable for concrete because it is lightweight and fulfills filler material in concrete. It is why the previous studies have significantly focused on the utilization of sawdust as filler in concrete. Another additive is steel fiber which has had significant applications in recent years to provide the uniform tensile strength of concrete. The concrete itself is weak in tension, making the steel fibers a very sustainable alternative to increase the sustainability in structures.

This study is focused on using sawdust and steel fibers in concrete to determine its mechanical characteristics. Sand is replaced by sawdust at 3%, 6%, 9% and 12% while steel fiber is added at 0.5%, 1.0% 1.5% and 2.0% by weight. The control samples were also prepared to compare the findings from the experimental investigation, which is carried out to find out compressive strength, tensile strength, and flexural strength. The results have shown that by increasing the percentage of sawdust, there is a significant decrease in all mechanical properties of concrete. Increasing the steel fibers also decreases the workability but increases the tensile strength. Therefore, it is recommended that the sawdust should not be replaced above 3%, while steel fibers must not be added above 0.5% as it affects the quality of concrete. However, sawdust should be used because it reduces concrete's weight and provides a sustainable solution to reduce waste.

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CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is the most used building material, and its sustainability is always required because of increasing challenges and the construction. The ingredients of the concrete are essential in providing adequate mechanical properties so that it can provide durable service life to the structures. With increasing concrete construction, the different materials to make up the concrete is growing because it is directly associated with environmental sustainability and robust growth to green building [1]. It is made up of natural resources, which has long-term consequences from the perspective of ecological sustainability. Therefore, the research is increasing to replace the materials with an alternative to save the environment. At the same time, the utilisation of Steel fibre in the concrete has also allowed the construction to improve the mechanical properties and ultimate durability of structures significantly [2]. Steel fibre provides the tensile strength to the concrete, which is one of the weaknesses of the material, and it fails major structural elements if not adequately addressed. Similarly, sawdust is another waste material that has properties that can replace the sand in the concrete.

1.1.1 Steel Fibre Reinforced Concrete

Concrete is good in handling compressive loads, and it is weak in providing adequate tensile resistance. It is why their reinforcement is significantly shod in the concrete to make it more durable and prevent it from brittle failure, which is known to be a devastating weakness of concrete. With the evolution of the research in concrete structures, the alternate sources of providing the tension are increasing [3]. One of the materials is steel fibre, which has similar properties to steel but makes the material more durable. Made up of a Steel wire with substantial thickness and shape, the Steel fibres provide the uniform characteristic tensile strength to the concrete, which is very efficient in increasing its practical application in the construction. Using the steel fibres in the concrete can be done effectively, and their needs to be distributed evenly in the structure so that significant tensile strength is obtained [4]. It is an undeniable fact that the addition of the Steel fibres provides the ability to the concrete to prevent the progression of the crack, which can lead to significant failures. Therefore, it is also one of the fundamental reasons to use Steel fibres in concrete to prevent loss. The reinforcement itself is not absent in stopping the correct progression and providing the required level of durability in concrete. Beside this the demand from the perspective of construction sustainability is also increasing [5]. The utilisation of the Steel fibre is being made in the concrete as it provides significant strength to the concrete in performing better as compared to ordinary reinforced concrete.

1.1.2 Saw Dust and Concrete

Every woodwork produces sawdust, and unfortunately, the allowed amount of it goes into waste, impacting the landfills. Although it is degradable in the environment, its destruction can be effectively utilised in other applications where sustainability is the primary concern [6]. Concrete is hefty if the conventional material is used, and therefore it is not appropriate from the perspective of the modern architectural designs and required level of sustainability. It is a reason that weight reduction is significant while maintaining the good mechanical characteristics of the concrete. Here the role of sawdust is vital because it can be effectively utilised in the manufacturing of lightweight concrete.

Furthermore, it has an efficient property of providing increased resistance to the fire, which is known to be the weakness of the concrete [7]. Because of its less weight, its utilisation can be effectively made in replacing filler material in concrete which is the sand. The significant utilisation of sand in the last decades has negatively impacted the environment, but it also provided adequate strength to the concrete [8]. But from the perspective of the utilisation of the waste product obtained from the woodwork, the demand is significantly present in the construction industry, which can be effectively utilised to reduce the waste and move the construction industry towards sustainability, which is the matter requirement future.

The combined effect of Steel fibre and utilisation of the sawdust in concrete needs to be known because the filler material is being replaced with a waste product. The concrete must have maintained its characteristic properties and not become less favourable as it would be not appropriate [10]. The purpose of the overall improvement in the concrete building material is to make it more sustainable and utilise other forms of waste products because it can deviate less from the characteristic properties when proper replacement is made with the waste materials.

1.2 Problem Statement

The weakness of concrete from the perspective of the tensile strength is one of the critical problems the modern construction industry is facing, and there is a need of increasing the tensile resistance in the concrete so that its practical utilisation can be increased according to the modern structural requirements. The utilisation of reinforcement in concrete does not provide uniform characteristics in achieving the tensile rigidity in the concrete. Using Steel fibres can provide the best solution to the problem.

Sawdust is a waste product that has its environmental concerns. At the same time, there is a significant amount of filler material utilised in the concrete, which does not contribute significantly to increasing the strength of the concrete. But the presence of filler is necessary for the concrete to make it rigid and function appropriately according to load handling requirements. Sawdust has the characteristic properties of the filler material. Still, its utilisation in conjunction with the Steel fibres in the concrete is not researched significantly. There is a need to solve the problem of maintaining the strength of the concrete while reducing its weight.

1.3 Research Objectives

- To determine the effect of incorporating the Steel fibres and saw dust in concrete on its mechanical properties.
- To determine the lightweight properties of the proposed concrete incorporating sawdust.

1.4 Research Significance

This research aims to significantly focus on developing the concrete, which is vital in tensile strength and has the sawdust added as a replacement material for the sand. This is to increase the sustainability of the concrete as it will minimise its weight and maximise the capacity by which it can be utilised to construct different structures [11]. The research is aim to provide the long-term perspective of the development of sustainable concrete, which can also solve the problem of adequately handling the waste of sawdust and also solve the problem of concrete that is lacking in terms of aggregate tensile strength and require a significant amount of reinforcement that is also not efficient in providing uniform characteristic tensile strength to the concrete.

1.5 Thesis Overview

Overall thesis is organised into the following sections.

- **Chapter 1:** This chapter includes a brief background of the research and a detailed description of the problem statement, Research objectives and thesis organisation. It is focused on providing background knowledge about utilisation of the Steel fibre and sawdust in the concrete.
- **Chapter 2:** This chapter is a related literature review from the perspective of the latest studies conducted on utilisation of the waste sawdust in the concrete and improvement of the concrete tensile strength by utilising Steel fibres. The critical analysis is done in this chapter to determine the research gap.
- **Chapter 3:** This chapter is about the detailed description of the research methodology based on its experimental investigation to determine the efficiency of utilisation of Steel fibres and sawdust in concrete.
- **Chapter 4:** After performing an experimental investigation, the results are presented in tabular and graphical form in this chapter. The purpose of this chapter is to ultimately deliver the effects based on which the discussion can be carried out to provide conclusive results about the thesis.
- **Chapter 5:** This chapter is dedicated to discussing and concluding the overall thesis results presented in the previous chapter. It also includes the recommendations and Research implications that are also very bottle for maximising the future sustainability of this thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Traditional Concrete

The importance of concrete is significantly increasing in structural engineering because of its sustainability associated with the lower cost and increased service life. But the significant deficiencies exist in the construction of concrete buildings where it does not provide adequate capacity to handle the tensile loads and has significantly heavyweight, limiting the size of the structures [12]. These are the two fundamental problems evident from the recent studies and considerably affect the concept of sustainability worldwide. Its heavyweight cannot be contributed effectively in the building of multi-storey buildings. It is concluded from previous study that the lightweight construction is also stated with cost, which is one of the essential narratives discussed in the studies to improve the concrete by other materials to provide more sustainability to the practical construction sector [13]. Although the reinforcement is utilised in a significant amount in the concrete, it does not give uniform tensile resistance to the concrete, which is the crucial property of the material that should be implemented in the modern perception.

Furthermore, there is no proper way of improving the tensile strength of concrete because the cement between the aggregates maintains the entire binding strength. This can contribute to brittle failure, which is also one of the crucial disadvantages of traditional concrete. It is evident that significant deficiencies exist in the conventional concrete because the tensile stress is inadequately and non-uniformly distributed within the structural members. That is because the reinforcement in the concrete is typically taken to a specific area and does not provide any uniformity to the concrete by which the cracks can be controlled [14]. The increasing damages and uncontrollable behaviour of the concrete while the reinforcement is placed in it creates the situation where the durability of the structures is affected. However, the standard is performing well in terms of providing significant resistance from the perspective of compressive strength. Still, at the same time, its reduced capability of handling the tensile load increases the overall construction cost. In terms of sustainability, traditional concrete is not practical and suitable material where the new architectural designs and structural requirements are in high demand.

2.2 Steel Fibre Reinforced Concrete

Fibres are widely utilised in concrete to improve the uniform strength of the material so that it can withstand the compressive and tensile load adequately. The significant deficiencies that exist during the reinforcement in the concrete can be easily covered by utilising the Steel fibre, which provides more uniformity in handling the tensile load that is considered the significant reason for brittle failure [15]. The utilisation of Steel fibres is going on in the concrete for more than two decades now. There is a substantial improvement in achieving better mechanical strength and for all good surface finish because it limits the crack progression and significantly increases the durability of the concrete. For this reason, Steel fibres are always categorised as the essential additive material that can increase the practical durability of the concrete according to recent applications [15]. The addition of the Steel fibre in the concrete is linked with providing more area of the Steel and concrete so that the uniform strength can be maintained from an individual element of the structures. However, it is also evident that significant deficiency exists in the utilisation of the Steel fibre when the proper construction method is not adopted. That is because the Steel fibres need to be distributed evenly in the structure of the concrete to provide uniform tensile strength to prevent the crack progression and achieve maximum strength [16]. Following the significant improvement in the strength of the concrete that happens because of the addition of the Steel fibre, it is essential to consider its future development as it is a very suitable material and can be added in low quantity compared to conventional Steel. Therefore, the advantage of the cost is also there in terms of improving the quality of the concrete by using Steel fibres, which is fully supported by the previous studies. From the perspective of the flexural strength, it is evident that the Steel fibres improves it effectively as they provide significant resistance to the lower part of the beams where the bending is maximum.

In recent years, significant development is being carried out to incorporate better construction practices by utilising Steel fibres to increase sustainability and maximise the structure's performance under tensile loading. It is an undeniable fact that fibre reinforced concrete is very effective in improving structural sustainability. There is also strong evidence of improvement in the impact resistance of the complete when the steel fibre is utilised [16]. Furthermore, the isotropic properties of the concrete are significantly maintained by the Steel fibres if they are appropriately distributed within the mesh of the concrete. This property is related to progress in the flexibility of the concrete as the brittleness is reduced due to the uniform behaviour of the concrete in handling the tensile load. The overall durability of the concrete is related to the utilisation of the fibre because it is a very effective way of reducing the cost and maintaining the significant level of strength of the concrete that can contribute to better development of the structures [17]. The Steel fibres have already minimised the cost of construction in various practical construction projects, due to which they are considered the essential replacement of the conventional enforcement. Still, the negative impacts associated with it also produce unwanted costs when any irregular placement occurs.

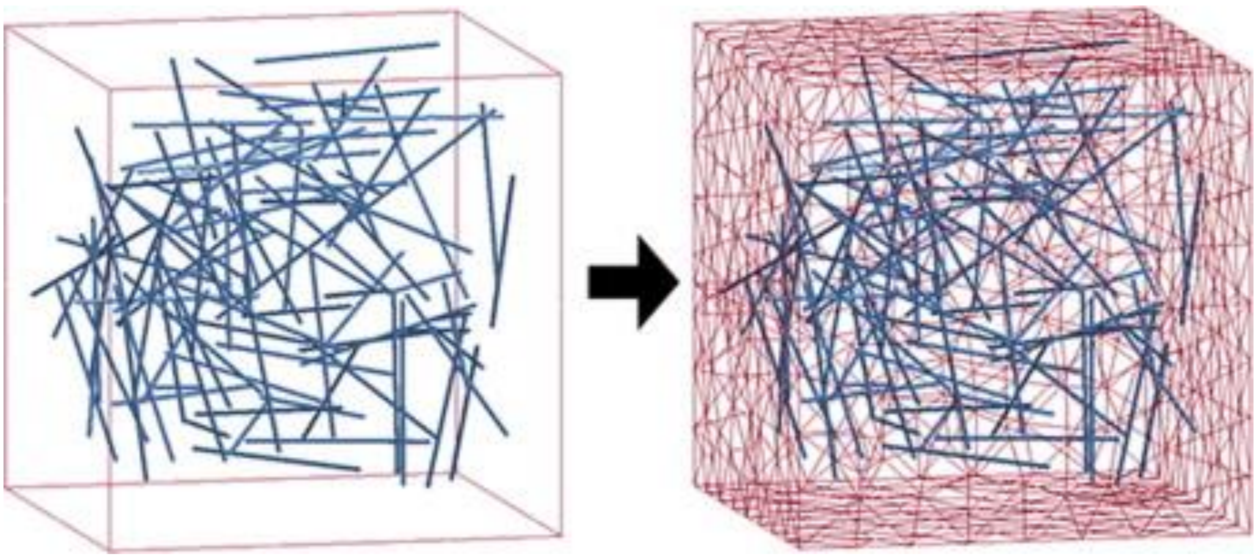


Figure 1: Steel Fibres in Concrete [9]

2.3 Saw Dust Modified Concrete

The saw dust is the important waste material obtained from the extensive woodwork, and there is no proper way of recycling it. Unfortunately, due to the improper applications existing in the world, the saw dust mostly goes to waste. A significant opportunity exists in utilising the saw dust in the concrete because it can achieve the considerable strength of the concrete while minimising its weight. According to recent studies, it is agreed that comparable strength is obtained from the compressive loading perspective when the conventional fine aggregates are replaced with saw dust. This is by far the critical achievement from the standpoint of concrete construction [18]. Using waste materials is significantly increasing in construction engineering because of their sustainability associated with the environment and the cost production characteristic that is very important for the overall construction. It is undeniable that the fine aggregates utilised in the concrete are only doing the job of filling the gaps between the coarse aggregates, which are bonded together by the cement. Recent studies have shown that the saw dust can be considered an important alternative that can be replaced in the concrete and can work efficiently to provide comparable characteristic strength [19]. But again, the implications exist from the perspective of improving the tensile strength of the concrete as the material does not constitute improving the flexural or tensile strength. Practically when the saw dust is utilised in the concrete, it significantly minimises the flexural and tensile strength. However, the overall reduction in the heat transfer happens because of the insulating characteristic of the saw dust.

Figure 2: Saw dust modified concrete [33]

Furthermore, analysing the microstructure of the saw dust, it is evident that it does not increase the compressive strength of the concrete because it is comparatively more flexible than the conventional particles of fine aggregates [19]. However, comparable mechanical properties are found by utilising the saw dust in the concrete, which also shows the significant research implications that can provide more sophisticated outcomes if used with any other replacement material that can cover the deficiencies. Therefore, the narrative in previous studies still exists in improving the search so that the material can effectively be utilised in the construction of concrete where the significant tensile and flexural strength does not matter. Still, they are not to the limits where it can be said that the saw dust is providing very significant properties as compared to traditional concrete [20]. It is the reason that the practical applications of saw dust modified concrete are related to the domestic construction where the loads are rare in the lower limits and can be effectively controlled to promote construction sustainability [21]. Therefore, the research gap points towards the effective utilisation of the saw dust. It provides more sustainable outcomes by reducing the weight of the structure and the cost associated with it and maintaining comparable mechanical characteristics.

2.4 SFRC with Saw Dust

There are various studies in which the steel fibre and saw dust combination are utilised to improve the concrete quality. Both are the material with different characteristic properties in terms of changing the mechanical strength of the concrete. Therefore, their combination is related to the optimal percentage at which they provide the specific improvement in the mechanical properties and after which they could not contribute to sustainability [22]. Steel fibre, as an essential material for improving the tensile strength of the concrete, has characteristic properties of affecting workability. When the workability of concrete is very high, it could not be placed in the construction activities properly, due to which a significant deficiency exists in terms of sustainable construction [23]. According to a study, it is evident that 3% addition is recommended because, after it, the substantial reduction in the properties of the material occurs, due to which the workability is highly affected.

Furthermore, when it is combined with the concrete in which the filler material is replaced with the saw dust, it affects the compressive strength behaviour of the concrete, which can be unpredictable in some cases. It is the reason that the previous studies have utilised different techniques to determine the behaviour of the material under stress because the steel fibres must provide increased tensile resistance to the concrete while the function of saw dust is to reduce the cost and also offer variable compressive strength characteristics to the concrete [24]. The utilisation of saw dust in the concrete is associated with a reduction in the tensile and flexural strength, which can be covered by utilisation for the steel fibre. Again, it is evident from the studies that the proper distribution of the steel fibres is necessary within the concrete match because it directly impacts the rigidity of the concrete, which can produce due to the use of saw dust in concrete. The limited research is done from the perspective of effective improvement in the characteristic of the concrete by adding both materials because Steel fibres show promising results.

Figure 3: Steel Fibre Reinforced Concrete after Failure [9]

In contrast, the saw dust does not constitute the critical property of the material that is the tensile strength. However, that research gap exists according to the recent studies showing the future implications of adequately changing the ratio of both materials to improve the characteristic strength of the concrete. But it is also a reality that the utilisation of saw dust in concrete that is effectively modified with steel fibres results in minimising the weight, which is also better from the perspective of maximising the applications of steel fibre reinforced concrete [25]. To maximise the environmental sustainability of the saw dust and improve the characteristic mechanical properties of the concrete, an effective combination of both of the materials must be made, which can provide long-term durability to the concrete that is also one of the critical factors in sustainability.

2.5 Environmental Sustainability

It is evident from the previous studies that were increasing the percentage of the saw dust in the concrete significantly minimise its thermal conductivity, and it is also better from the perspective of using the waste material appropriately. But at the same time, thermal conductivity is not an essential property from the standpoint of structural sustainability. However, from the sustainability perspective, the thermal conductivity itself is one of the critical factors that can also produce better outcomes in minimising energy conservation within the buildings [25]. According to a study, it is evident that the 10% of the replacement of saw dust in the concrete has created a very significant decrease in the thermal conductivity. Still, at the same time, the results from the compression strength perspective also reduced, which puts a question mark in terms of using the saw dust in large percentage in the construction work. The research implications of the latest studies show that a meagre portion of the replacement of saw dust is recommended because it can decrease the weight of the concrete and reduce the thermal conductivity [26]. But replacing a large number of fine aggregates with the saw dust for completely replacing the fine aggregates with the saw dust is not recommended by the previous studies. It can significantly minimise the sustainable construction of the concrete. The same behaviour is observed while dealing with the split tensile testing as it also reduces the minimal results when the percentage of the saw dust replacement increases [27]. Concrete has already meagre resistance in handling the tensile loads, and the significant impact that occurs due to usage of the most miserable in concrete is not acceptable from the perspective of sustainability. However, comparable results are obtained when the minimal replacement is happened in the concrete by keeping the content of the saw dust to the minimum level, which does not affect the tensile strength of the concrete.

In contrast, the utilisation of Steel fibres has created a more sustainable environment for the concrete to be utilised in most structural applications because it maximises the tensile strength of the concrete, which is its major weakness. Previous studies have categorised Steel fibre as the essential material that tends to entirely or partially replace the reinforcement from the concrete because it provides a greater modulus of elasticity which is needed for better ductile behaviour in the concrete [28]. However, by using both materials, it is evident from the studies that cost reduction can occur, which is one of the essential concerns from the perspective of modern concrete construction. And most educated design as the Steel fibre itself is promising new and theme structure elements that require vast quantities of concrete by providing the same level of strength. Both at the low percentage the direct impact on the characteristic mechanical properties of the concrete cannot happen from the negative perspective [29].

2.6 Future Applications

From the future perspective, it is evident from the studies that are significant applications of the concrete exist that is modified with the saw dust as it can promise reduced thermal conductivity that is also better for the energy efficiency. It is also better from the perspective of minimising the weight of the structure. Recent studies have shown that future construction will require the minimisation of the cost because it is one of the critical factors by which most construction projects can quickly fail [30]. Therefore, the outcomes of utilising the Steel fibres in combination with the saw dust are promising. A significant reduction in the waste of saw dust can also occur as the quantity of field construction will significantly increase in the future. It is the reason that the research implications are particularly aligned with the improvement of the concrete construction sustainability as it is already critical vital for it to improve the durability and long term service life of the structures. Although the scientist does not provide any significant strength from compression or tensile, it can reduce the cost [31]. According to the research, when effectively used in combination with steel fibres, it is evident that the overall sustainability can be increased to the optimal level where the concrete can perform better than the traditional one. The innovative developments in concrete technology are critical evidence from the latter studies due to which the significant improvement in the substantial rigidity happens while using the Steel fibres [32]. Therefore, future implications will promote construction sustainability as the latest studies show comparable results at low percentages.

2.7 Previous Studies on Saw Dust and Steel Fibre Concrete

The appropriate literature survey shows that several research studies on Saw Dust and Steel Fibre Concrete have been conducted as under,

Ambika Nahak et al. conduct the experiments on concrete made with standard Portland cement and partial replacement with ash of sawdust ranging from 5 to 20% and with 0,5% steel fibre again at levels of 1 %, 1.5 percent, and the same SDA level were explored. The concrete grade M25 was specified for this project, and it was used throughout the building. In addition to compressive strength, split tensile strength, and flexural concrete strength testing on new concrete, additional tests have been carried out on it, including slumping and compacting factor tests. Testing for normal and SDA-concrete pressure, as well as split tensile strength, was done at the ages of 3, 7, 28 and 56 days, and the results were analysed. The evaluation of SDA-containing steel-fibre concrete was carried out across three distinct time periods: three days, seven days, and 28 days. The bending strength of saw dust ash concrete with and without steel fibre was tested after 28 days of curing time in the laboratory. As the quantity of saw dust ash grows, the strength of the material, according to the experimental results, diminishes. By contrast, when a steel fibre is added to the SDA, the concrete has double the strength of the SDA at the third, seventh, and twenty-eighth days, as compared to the FRSDA concrete.

Prateek Agrawal et al. conduct experiments on Conventional concrete manufacture involves rough materials, fine aggregates, cement and water. But this standard concrete needs strength, but at the same time it is both costly and environmentally unfavourable. Consequently, this article is an experimental analysis on saw dust, partially substituting cement, respectively in proportions of 5%, 10% and 15%. In addition to increasing the amount of concrete strength steel fibres by 0.5%, 0.75% and 1% is added by volume of concrete.

Kho Pin Verian et al. work on Cement's compressive strength (fc) and partition elasticity (fspt) are two major foundation constraints that must be considered. Due to the difficulty, expense, and time-consuming nature of elastic testing, a number of specialists are interested in predicting an improved but accurate estimate of the property. For example, non-straight relapse, fake neural organizations (ANN), supporting vector machinery (SVM), and model tree (MT) M50 have all been investigated in order to estimate the elasticity (fspt) of concrete produced with and without the addition of steel fibre. Mistake measures were used to evaluate the presentation of various models, including those created and constructed by a variety of analysts. The results reveal that the partition elasticity of concrete made with and without steel fibre supports can be predicted with sufficient accuracy using non-direct relapse exam, falsified neural organization, vector support machine, and model tree computing.

Osama A. Abaza et al. investigate the flexural load-avoidance conduct of steel fibre supported rubber treated cement (SFRRC) up to the main break load. In particular, this investigation utilized a trial technique to analyse concurrent flexural load-avoidance reaction estimations on typical

Portland concrete cement (PCC), rubber treated cement (RC), steel fibre supported cement (SFRC), SFRRC, and others.

Maldas et al. investigates the mechanical characteristics of pressurized polystyrene loaded with the accumulation of softwood and hardwood species. The 0.1 strain malleable modulus and elasticity, lengthening and power at the yield point are taken into account. The adequacy of sawdust wood as a thermoplastic filler has been examined using two different mesh sizes (20 and 60, as well as altering the weight level of strands from 10 to 40. Moreover, several medications (for example, joining copolymerization) and coupling experts (for example quiets and isocyanates at varied foci) were used to increase wood strand similarity with the polymer networks. The degree to which mechanical qualities are improved relates to fibre stacking, the fibre molecule size, the emphasis and synthetic design of the coupling experts, and if specific medications (for example, fibre coverings, fibre connections) are used. The mechanical characteristics of the composites are increased to 30 by filaments with a grid size of 60 and 3 isocyanates.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Overview

The purpose of this section is to focus on the research methodology which is adopted to achieve research objectives. The standard test methodology is followed throughout the experimental investigation, which was necessary to complete the research objectives and produce conclusive results that are very useful from the perspective of the future implications. This section provides a detailed explanation of the different materials utilised in the testing procedure with further detail about the data collection and analysis procedure, which is very important in providing sustainable results.

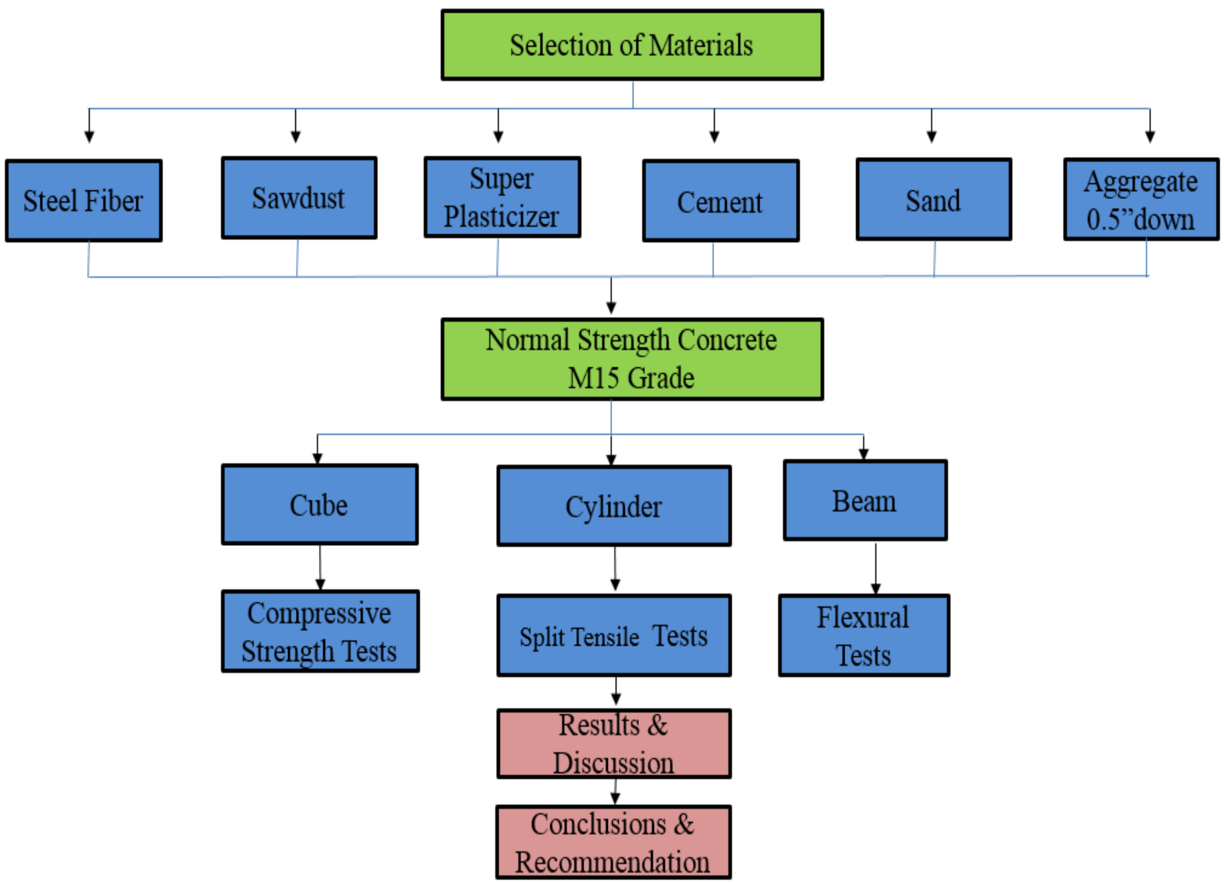


Figure 4: Experimental Program

3.2 Specimen

Total 40 specimen are prepare for testing with different percentages of saw dust and steel fibres. The details of specimen are given below in table.

Table 1: Dimensions Details of Specimen

Name of Specimen	No of Specimen	Length (mm)	Width (mm)	Height (mm)	Volume (m^3)
Cube	15	150	150	150	0.003375
Beam	10	700	150	150	0.01575
		Diameter (mm)		**Height (mm)**	**Volume (m^3)**
Cylinder	15	150		300	0.0053013

Table 2: Mix Proportions for Concrete Specimen

MIX PORPORTION	CEMENT : FA : SD : CA : SF (BATCHING BY WEIGHT)
0% S.D and 0% S.F	1:2:4
3% S.D and 0.5% S.F	1 : 1.97 : 0.03 : 3.995 : 0.005
6% S.D and 1% S.F	1 : 1.94 : 0.06 : 3.98 : 0.01
9% S.D and 1.5% S.F	1 : 1.91 : 0.09 : 3.98 : 0.015
12% S.D and 2% S.F	1 : 1.88 : 0.12 : 3.97 : 0.02

3.3 Materials

All the materials for this study were significantly verified from the quality perspective because it was necessary to ensure that the maximum quality is maintained throughout the experimental investigation so that the results are fully reliable. It was also important because the different batches of the material have quality differences, affecting the sustainability of the final results.

Therefore, before selecting the proper material, different suppliers were evaluated, and the proper material selection is made to fulfil the study's objectives. The different materials utilised in the manufacturing of the concrete add as replacement materials are obtained in bulk amount according to the requirements of the experimental investigation so that any material that cannot affect the efficiency of the research.

3.3.1 Cement

The ordinary Portland cement is utilised to manufacture concrete with the maximum strength after 28 days is 20 MPa. This type of cement is adequate in terms of providing significant seconds to the final concrete, and it is also widely utilised as a construction material when the practical construction work is being carried out. It was also available according to the required quantity, and therefore, it is selected based on its proper quality. After obtaining it from the suppliers, the quality tests were carried out to determine the cement's final and initial setting time. It was found that it has an initial set of around 27 minutes and 45 seconds, while the maximum final setting time is obtained at 360 minutes and 49 seconds. Both values are in the applicable range according to the standard ASTM procedures. The compressive strength test is also carried out to determine the actual capacity of the payment. It is calculated that the results are adequately aligned with the requirements of the concrete.

Table 3: Setting Time of Cement Test Result

Sr. No	Detail of Test Conducted	Results
1	Standard Consistency	24% (standard temperature)
2	Setting time	
	i. initial setting time	27 min 45 sec
	ii. final setting time	360 min 49 sec
3	Specific gravity	3.807
4	Average compressive strength in MPa	
	i. 3 days’ strength	37
	ii. 7 days’ strength	46.5
	iii. 28 days strength	63

3.3.2 Fine Aggregates

The fine aggregate is a filler material in the concrete. It was very important to select it from the perspective of the very fine quality so that it does not affect the final results of the concrete [34]. It is why the Chenab river sand is utilised as the fine aggregate because it has significantly better properties than other types of sand available in the local area. The specific gravity of the concrete is calculated to be 2.6. Furthermore, the fine aggregate's fineness modulus is calculated using the sieve analysis, and it is estimated to be around 3.04. After verifying all the quality checks on the fine aggregate, it is then further analysed to determine the specific gravity. The actual specific gravity is 2.62 as compared to the predicted specific gravity, which was 2.6. The measurement of the water absorption of the fine aggregate is also carried out, and it is estimated that the fine aggregate is 1.63 per cent water absorbent. The detailed analysis of the chemical composition of the fine aggregate is also compared with the standard data. It is found that the fine aggregate lies according to the needs of manufacturing the concrete with high quality.

Table 4: Particle Size Analysis of Fine Aggregates

Sieve #	Sieve Size	Weight Retained	%age Weight Retained	Com %age wt. retained	%age Passing
#4	4.76	0	0.00	0.30	99.70
#8	3.36	0	0.00	0.30	99.70
#10	2.00	0	0.00	0.30	99.70
#16	1.19	0	0.00	0.30	99.70
#30	0.595	0	0.00	0.30	99.70
#40	0.42	5.2	1.34	1.64	98.36
#60	0.25	37	9.51	11.15	88.85
#100	0.149	307.1	78.93	90.07	9.93
#150	0.105	34.6	8.89	98.96	1.04
#200	0.074	5.2	1.34	100.30	-0.30
total		389.1		303.62	

Fineness Modulus of Fine Aggregate	Cumulative %age wt. retained/100
Fineness Modulus of Fine Aggregate	3.04

Table 5: Specific Gravity of Fine Aggregates

Description	Symbol	Weight (gm)
wt. of sample	C	500
wt. of pycnometer + sample + water	A	1924
wt. of pycnometer + water	B	1612
After 24 hours wt. of sample	D	492
Specific Gravity of Fine Aggregate:		D/C-(A-B)
Specific Gravity of Fine Aggregate:		2.62

Table 6: Water Absorption of Fine Aggregates

Description	Symbol	Weight (gm)
wt. of sample	C	500
wt. of pycnometer + sample + water	A	1924
wt. of pycnometer + water	B	1612
After 24 hours wt. of sample	D	492
Water absorption of fine Aggregate:	(C-D/D)*100	
Aggregate water absorption	1.63	

3.3.3 Coarse Aggregates

The coarse aggregate is an important constituent of the concrete, which carries all the load. Therefore, its quality needs to be maximum so that the ultimate impact on the final quality of the concrete can be increased. The Margalla Adhi crush is utilised, which is known as the best type of aggregate in the local area. Practically this aggregate is used widely in structural concrete construction because of its very efficient properties according to the structural applications. After obtaining the aggregates, the sieve analysis test is conducted to determine the fineness modulus and observe the quality of the aggregate whether they are being graded or not [35]. After performing the seed analysis, it is determined that the fineness modulus of the coarse aggregate was 1.6. The tests of the quality but also performed in which the practical experimental investigation is carried out to determine the shape and moisture content, which was also crucial because it directly impacts the water-cement ratio of the concrete. A detailed investigation of the specific gravity of the coarse aggregate is also carried out by which it is estimated that the specific gravity of the coarse aggregate is 2.6. This value is within the required limits because the normal aggregate has this amount of density that can provide significant returns to the concrete and perform better while handling the compressive loads. The water absorption test is also carried out on the coarse aggregate. The percentage of water could be determined that aggregate will absorb as the concrete will be manufactured. The absorption of the coarse aggregate is found to be 0.6 per cent. All the coarse aggregate quality is verified from the perspective of the standard values, after which the material is utilised in further experimentation procedures.

Table 7: Particle Size Analysis of Coarse Aggregates

Sieve no	Sieve size	Weight Retained	%age Weight Retained	Com %age wt. retained	%age Passing
2.5"	2.5	0	0	0	100.00
2"	2	0	0	0	100.00
1.5"	1.5	0	0	0	100.00
1"	1	0	0	0.00	100.00
0.75"	0.75	20	1.17	1.17	98.83
0.5"	0.5	92	5.39	6.57	93.43
0.375"	0.375	782	45.84	52.40	47.60
0.1875"	0.1875	812	47.60	100.00	0.00
PAN		1706		160.14	
	Fineness Modulus of Corse Aggregate				1.60

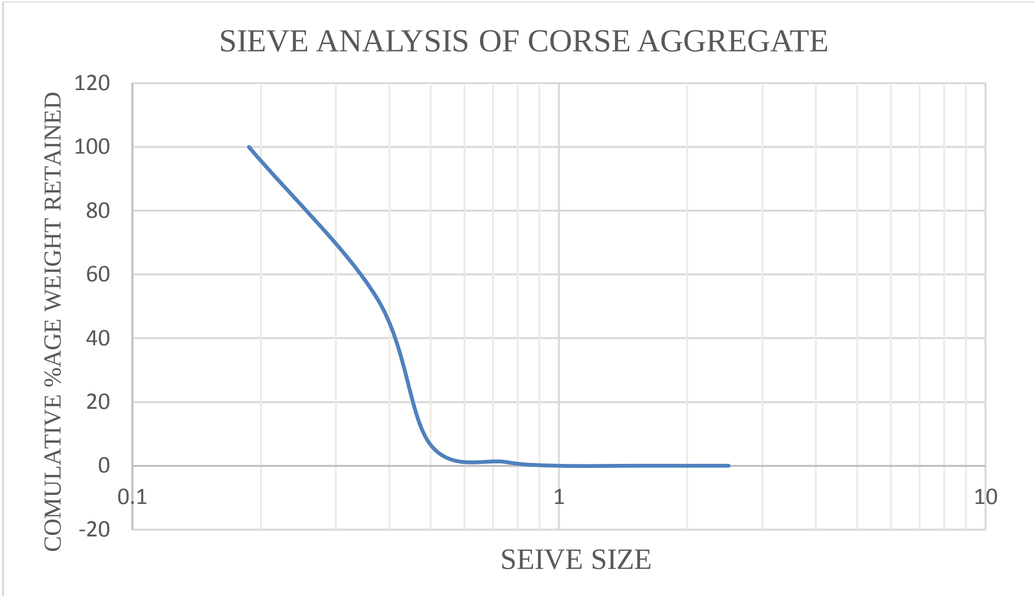


Figure 5: Sieve Analysis of Coarse Aggregate

Table 8: Specific Gravity of Coarse Aggregates

Specific Gravity of Coarse Aggregate:		**Weight (gm)**
wt of sample	C	1000
wt of pycnometer + sample + water	A	2154
wt of pycnometer + water	B	1536
After 24 hours wt of sample	D	994
Specific Gravity of corse Aggregate:		D/C-(A-B)
Specific Gravity of corse Aggregate:		2.60

Table 9: Water Absorption of Coarse Aggregates

Water Absorption of Coarse Aggregate:		**Weight (gm)**
wt of sample	C	1000
wt of pycnometer + sample + water	A	2154
wt of pycnometer + water	B	1536
After 24 hours wt of sample	D	994
Water absorption of fine Aggregate		(C-D/D)*100
Water absorption of Coarse Aggregate:		0.60

3.3.4 Saw Dust

The selection of the saw dust was very important because the overall desert objective relies on its better quality. Therefore, from the waste perspective, it is obtained and then further analysed from multiple quality checks. Fortunately, the saw dust has the significant capacity to have a comparable property like the fine aggregates and therefore receive the type of testing procedure are adopted to determine its quality [36]. Initially, the fineness modulus of the saw dust is calculated by conducting the sieve analysis, and it is found that the fineness modulus of the saw dust is 3.97. The specific gravity test is applied, and it is estimated that it has a specific gravity of 0.79, which is significantly less than the ordinary fine aggregates utilised in the manufacturing of concrete in this study. This test also justifies the property of the saw dust because it has a significantly important characteristic of minimising the weight of the concrete, which is important in the maximisation of structural sustainability. The water absorption test of the saw dust is carried out. It is estimated that around 47.06 % is the absorption capacity of the saw dust, which is significantly higher than any other material being utilised in the research. The high absorption capacity is because of the dryness of the saw dust as it is directly obtained from the wood.

Table 10: Particle Size Analysis of Saw Dust

Sieve no	Sieve size	Weight Retained	%age Weight Retained	Com %age wt. retained	%age Passing
#4	4.76	4.7	2.35	0.30	99.70
#8	3.36	6.7	3.35	3.65	96.35
#10	2.00	7	3.50	7.15	92.85
#16	1.19	2.8	1.40	8.55	91.45
#30	0.595	15.4	7.70	16.25	83.75
#40	0.42	41	20.50	36.75	63.25
#60	0.25	36	18.00	54.75	45.25
#100	0.149	41.2	20.60	75.35	24.65
#150	0.105	42.1	21.05	96.40	3.60
#200	0.074	3.1	1.55	97.95	2.05
Pan		200		397.10	
			Fineness Modulus of saw dust		3.97

Table 11: Specific Gravity of Coarse Aggregates

Specific Gravity of Coarse Aggregate		Weight (gm)
wt of sample	C	125
wt of pycnometer + sample + water	A	1630
wt of pycnometer + water	B	1612
After 24 hours wt of sample	D	85
Specific Gravity of SAWDUST:		D/C-(A-B)
Specific Gravity of SAWDUST:		0.79

Table 12: Water Absorption of Coarse Aggregate

Water Absorption of Coarse Aggregate		Weight (gm)
wt of sample	C	125
wt of pycnometer + sample + water	A	1630
wt of pycnometer + water	B	1612
After 24 hours wt of sample	D	85
Water absorption of SAWDUST:		(C-D/D) *100
Water absorption of SAWDUST:	47.06	

3.3.5 Steel Fibres

Steel fibres have different shapes according to the requirements and specific applications. The Steel fibres that have increased capacity to resist the tensile forces always have a bend or twist in their shape. It is very important to improve the rigidity when it is effectively utilised in the concrete structure. A normal Steel fibre can be straight, but it cannot be effectively utilised incomplete construction because it slips through the concrete when any force is applied [37]. Therefore, this study the Steel fibre, which has the hooked and is utilised because they have increased tensile resistance and provide significantly better capacity to the concrete in maximising its performance and durability. The diameter of the Steel fibre utilised in this study is around 0.5 to 1 mm, which is significantly important compared to the other type of reinforcement added into the reinforced concrete. The tensile strength of the steel fibre is estimated to be around 1,000 megapascal which is typically important in improving the seductive sustainability when it is utilised in the concrete to provide increased resistance [38]. The carbon content is low, and there is no significant coating on the steel fibres, preventing them from rusting for any other degrading phenomena when exposed to the environment. Practically this type of Steel fibre has significant advantages for this study because it can provide increased crack strength and also have the capacity to significantly increase the capacity of the concrete in handling more compressive and tensile loads. The other types of Steel fibres are neglected for this study because they have specific disadvantages from the perspective of reducing the tensile strength of the concrete, and they are not utilised in the previous studies, which were focused on maximising the capacity of the concrete in handling the tensile loads.

Figure 6: Hooked Steel Fibres

3.4 Specimen Preparation

3.4.1 Specimen Mix Ratios and Quantity

Table 13: Quantity of 0% SD & 0% SF

Material	Proportion	Cube	Qty	Cylinder	Qty	Beam	Qty
Cement	1	3	3.3	3	5.19	2	11
Sand	2	3	7.5	3	11.73	2	24.94
Saw Dust	0	3	0	3	0	2	0
Corse Aggregate	4	3	14.97	3	23.49	2	49.88
Steel Fibre	0	3	0	3	0	2	0

Table 14: Quantity of 3% SD & 0.5% SF

Material	Proportion	Cube	Qty	Cylinder	Qty	Beam	Qty
Cement	1	3	3.3	3	5.19	2	11
Sand	1.97	3	7.23	3	11.4	2	24.2
Saw Dust	0.03	3	0.0747	3	0.1173	2	0.3738
Corse Aggregate	3.995	3	14.85	3	23.37	2	49.62
Steel Fibre	0.005	3	0.0249	3	0.03915	2	0.1247

Table 15: Quantity of 6% SD & 1% SF

Material	Proportion	Cube	Qty	Cylinder	Qty	Beam	Qty
Cement	1	3	3.3	3	5.19	2	11
Sand	1.97	3	7.05	3	11.01	2	23.42
Saw Dust	0.03	3	0.15	3	0.2346	2	0.7476
Corse Aggregate	3.995	3	14.79	3	23.25	2	49.34
Steel Fibre	0.005	3	0.0498	3	0.0783	2	0.2493

Table 16: Quantity of 9% SD & 1.5% SF

Material	Proportion	Cube	Qty	Cylinder	Qty	Beam	Qty
Cement	1	3	3.3	3	5.19	2	11
Sand	1.91	3	5.45	3	11.46	2	23.46
Saw Dust	0.09	3	0.6723	3	0.3519	2	1.12
Corse Aggregate	3.98	3	14.71	3	23.13	2	48.99
Steel Fibre	0.015	3	0.0747	3	0.117	2	0.3739

Table 17: Quantity of 12% SD & 2% SF

Material	Proportion	Cube	Qty	Cylinder	Qty	Beam	Qty
Cement	1	3	3.3	3	5.19	2	11
Sand	1.88	3	5.25	3	11.05	2	22.98
Saw Dust	0.12	3	0.8964	3	0.4692	2	1.49
Corse Aggregate	3.97	3	14.1	3	22.99	2	48.22
Steel Fibre	0.02	3	0.0996	3	0.156	2	0.5

3.4.2 Mixing and Casting of Samples

For effective designing of the specimen, the different mix ratios are calculated for each designated specimen. The ordinary sand is replaced with saw dust to get its behaviour from the compressive and other mechanical properties of the concrete. The variation in the saw dust is started from 0 % to 12% at the maximum limit because it is evident from the studies that after this limit, there is a significant reduction in the setting for the concrete, which is not desirable in any case. Practically the five different types of mix ratios are being implemented in which the Steel fibre is also increased from 0 % to 2% in total. The previous studies are utilised in making the mix ratios adequate because they directly impact the performance of the concrete with needs to be evaluated in further testing procedures. The detailed calculations of the individual quantity of different cylinders and the beams are carried out. For the compressive strength test, the cubes are desired, due to which for individual specimens, the three different samples are prepared to get the average quantity.

Similarly, for the splitting tensile test, it is required that the cylinders should be prepared of the concrete due to which three cylinders are prepared for each of the mixes. For flexural strength, test beams are required for the standard dimensions, which are also prepared under the requirements of the testing procedure, and their quantity was limited to 2. The sample design process and the mix ratios calculated in conjunction with the previous studies show that the outcomes can be useful from the perspective of the future implication of this research. It is taken care that the high amount of saw dust and steel fibre personal be added to the country because they can significantly reduce the characteristic mechanical strength and workability of concrete. The detailed quantities and the proportions of the different materials utilised in the individual mix ratio are below.

The mixing and casting process of the samples is very important in getting adequate results because it directly impacts the performance of the concrete. Therefore, it’s manufacturing needs to be carried out with maximum accuracy. Following the standard mixing methods, the laboratory mixture is utilised to mix the different constituents. The process of mixing starts from the preparation of the control sample in which there is 0% of the saw dust and 0% Steel fibre is added. Great care is taken while preparing the control samples because they are significantly critical in providing the benchmark from where the results are entirely compared. Following the needs of the preparation of the concrete mix, the different samples are cast for the single ratio on a single day so that their track record can be maintained. To practically implement the curing process, it is taken care that the individual samples must be cared for on different days according to the requirements. Twenty-eight days is the standard limit of the compressive strength test where it is measured. Therefore, the different samples are cured for around 28 days so that significant testing can be carried out according to the expected outcomes. The load-carrying behaviour of the samples also needs to be observed at the minimum curing days, due to which they are also cured and tested at fewer curing periods. The quantity of the overall addition of saw dust and the Steel fibre is kept to the maximum of 12% and 2% because it is an optimal limit after which is the country does not remain in the sustainable range.

Figure 7: Mixing of Concrete

Figure 8: Casting of Cubes

Figure 9: Casting of Cylinders

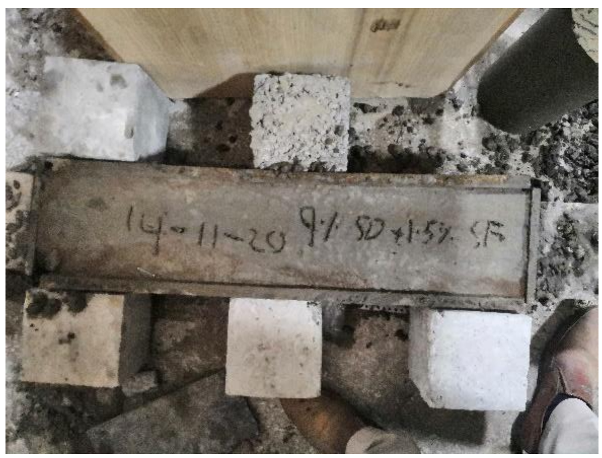


Figure 10: Casting of Beam Prism

Figure 11: Curing of Specimen

3.5 Data Collection

The Data collection procedure involves contacting the experiments and taking the results concerning the specific specimens and their curing periods. The laboratory equipment is combined with sophisticated software to get the results and then analyse them properly so that sustainable outcomes can be established from the research perspective. The behaviour of the concrete is judged from the perspective of compressive strength, splitting tensile strength and flexural strength. All these mechanical properties are critical in improving the sustainability.

3.5.1 Universal Testing Machine (UTM)

The universal testing machine is the main component of the experimental procedure because it has contributed effectively to the results. All the tests can be easily carried out by just changing the assemblies. The WAW-500PC controlled universal testing machine is used as it is very advanced in providing accurate results as much as possible. It is one of the important qualities of the machine that it can perform the test on different types of samples and maintain the testing procedure at the maximum. The machine is properly utilised to test the compression splitting tensile and flexural strength tests by utilising the proper assemblies. The C type loading friend is also very critical from the perspective of improving the machine's sustainability. Therefore, it has a very sophisticated measuring system to provide the conclusion results, which can be effectively used to determine the behaviour of the concrete. The applications of the overall testing procedure are significantly higher because it can be utilised in various types of mechanical tests of the concrete. It is the reason that the machine is utilised in high-intensity force testing because the uniform loading is applied on the sample to get sustainable results. Furthermore, the machine has significant applications in improving the digitised results, which can be further evaluated on the computer and converted into Excel format, which can be very helpful in making the graphs manually.

Figure 12: Universal Testing Machine

3.5.2 Using WAW Series Software

The software is the backbone of the overall measuring process implemented in the universal testing machine. It worked based on the window operating system by significantly getting the behaviour of the individual sensor connected to the machine. The load-displacement curve is the outcome of the machine because it is very crucial to determine the behaviour of the samples when the load is applied, and deformation occurs in them. The software is significantly controllable from the perspective of the computer screen, and it provides a very effective user interface that tends to suit the user. There is also complete overload protection and the stock condition settings that are very effective in providing accurate calibration to the testing procedure and significantly increasing the sustainability of the results. The final testing report is prepared by utilising the software, which has the ultimate benefit of getting the comprehensive result of the overall testing procedure. Therefore, this software has provided a significant opportunity to get the result very precise.

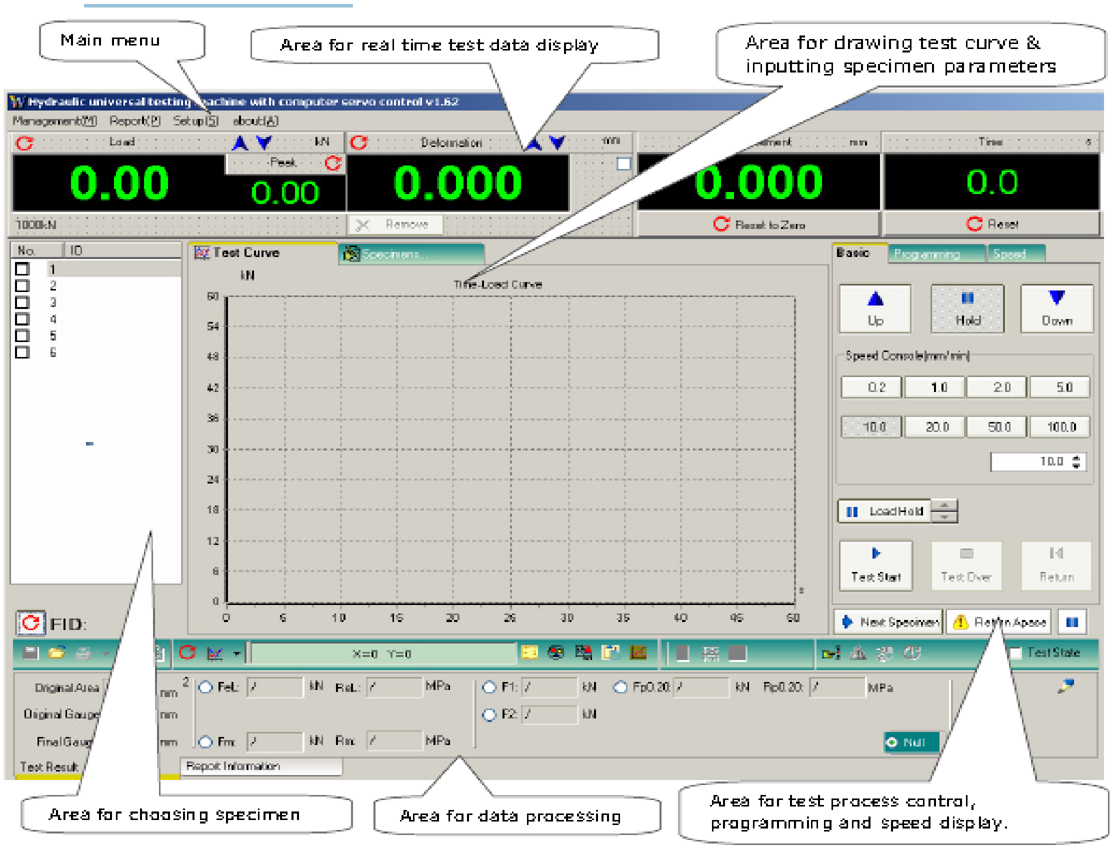
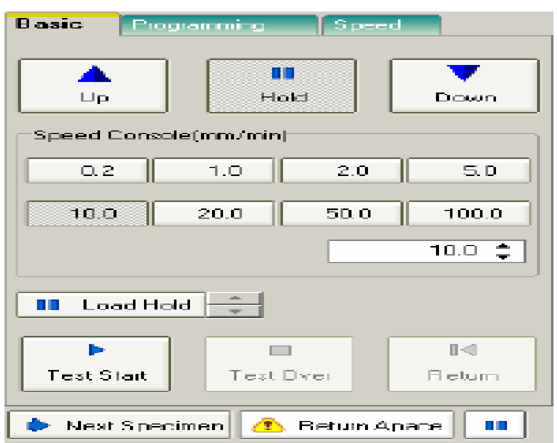
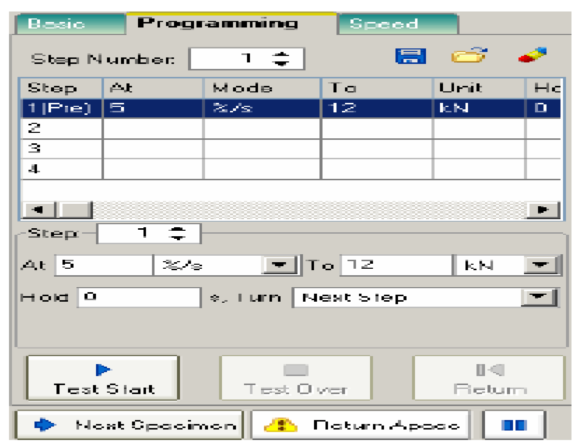
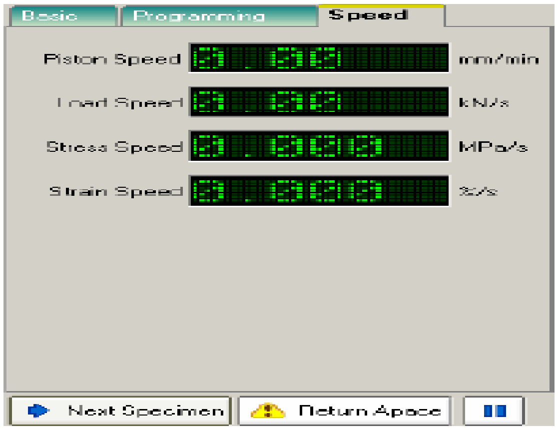


Figure 13: Software Interface







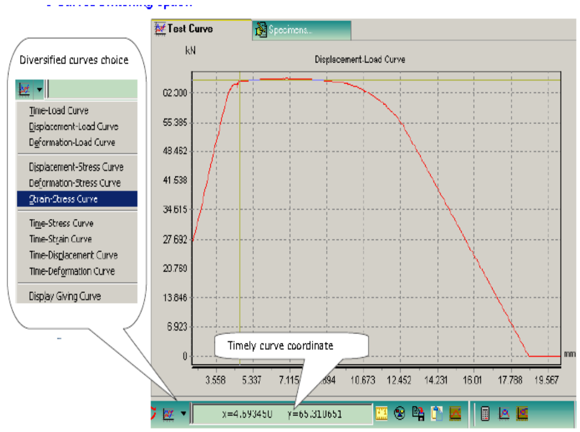


Figure 14: Software Functions

3.6 Data Analysis

The detailed comparative analysis of the data is carried out using the values obtained from a universal testing machine of the individual test conducted on each specimen. The load-displacement curve and the overall behaviour of the concrete under the individual test are evaluated so that recommendations can be provided. The overall testing process was aligned with the standard methodology due to which that analysis also considered the simple comparative analysis approach, and it is the reason that it has provided significant opportunity to maximise the performance of the experimentation process and also help to incorporate a better analytical approach in reaching the final analysis. The goal of the overall comparative analysis was to determine the increment or decrement in the performance of the concrete when the saw dust or steel fibre is added, and it has completely fulfilled its objectives according to the need of the study

CHAPTER 4

DISCUSSION & RESULTS

4.1 Overview

After performing the experiments, the results are obtained, and they are fully integrated into the graphical representations so that they could be easy to understand. This section outlines the results from the perspective of compressive strength, tensile strength and flexural strength. The detailed numerical data obtained from the analysis is presented along with the proper variation in the different test samples utilised in the experimentation. The overall results were obtained with maximum accuracy and according to the standard abroad required to get reliable results.

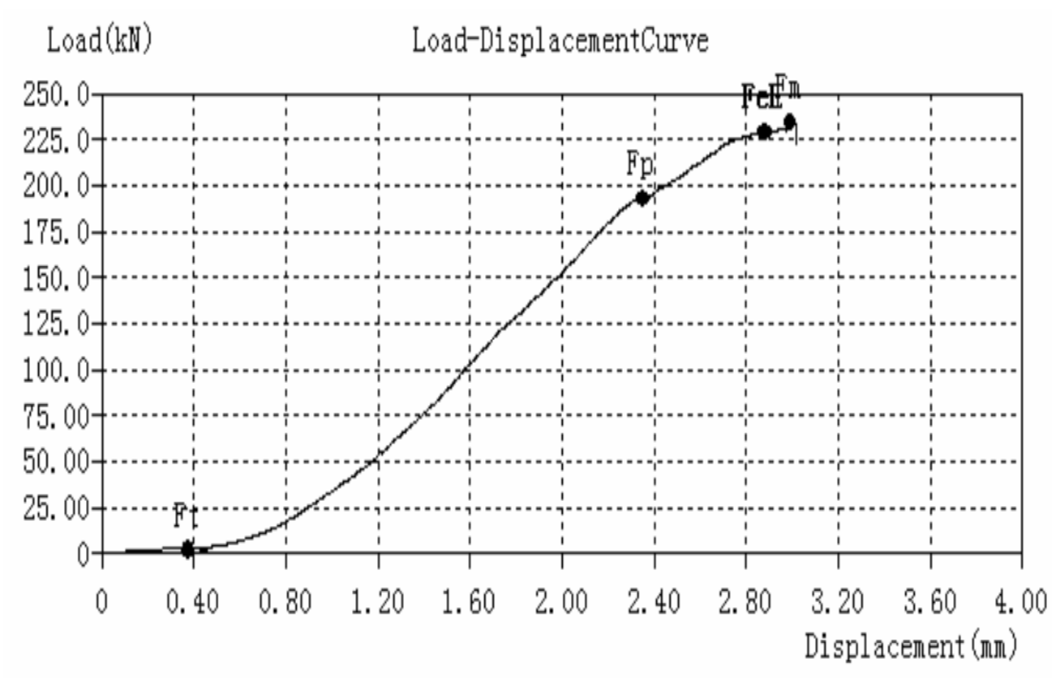


Figure 15: Result Format

Ft= lower cracking point — Δt= change in length at lower cracking point

Fp= yielding point — Δp=change in length at yielding point

Feh= ultimate yielding point — Δeh=change in length at ultimate yielding point

Fm=fracture point — Δm=change in length at fracture

4.2 Comparison of Cube Specimen at 0% SD and 0% SF

The following table shows a comparison between the results of the compression test of three cubes without the addition of sawdust and steel fibre. The highest value of load supported by a cube R1 is 235 kN. Change maximum load is higher as compared to the other two samples in R1. However, a significant variation exists in R2 while the pack is starting at 17.3. Overall the performance of the R1 cube is better as compared to the other two.

Table 18: Compressive Strength Result (0% SD & 0% SF)

Value		R 1	R 2	R 3
Lower Cracking Point	Ft	5	17.34	0
Yielding Point	Fp	193.3	66	75
Ultimate Yielding Point	FeH	229.5	200.3	212.5
Fracture Point	fm	235	200.4	216.3
Change in Length at Lower Cracking Point	Δt	0.38	0.25	0.27
Change in Length at Yielding Point	Δp	2.38	0.72	0.88
Change in Length at Ultimate Yielding Point	Δeh	2.9	1.6	1.3
Fracture Point	Δm	3	1.62	1.33

The load-deformation curve obtained from the experiment indicates that the R1 cube has the steepest angle as compared to the other two cubes. The behaviour is also necessary to note as the definition is consistent with the application of the load and under the elastic limit till the yielding point reached 193.3 kN. The load-deformation curve indicates that the better performance of the R1 can be attributed to the better concrete about the other two samples. It can be said that all versions of the concrete having no saw dust and steel fibre, can resist the load of 235 kN.

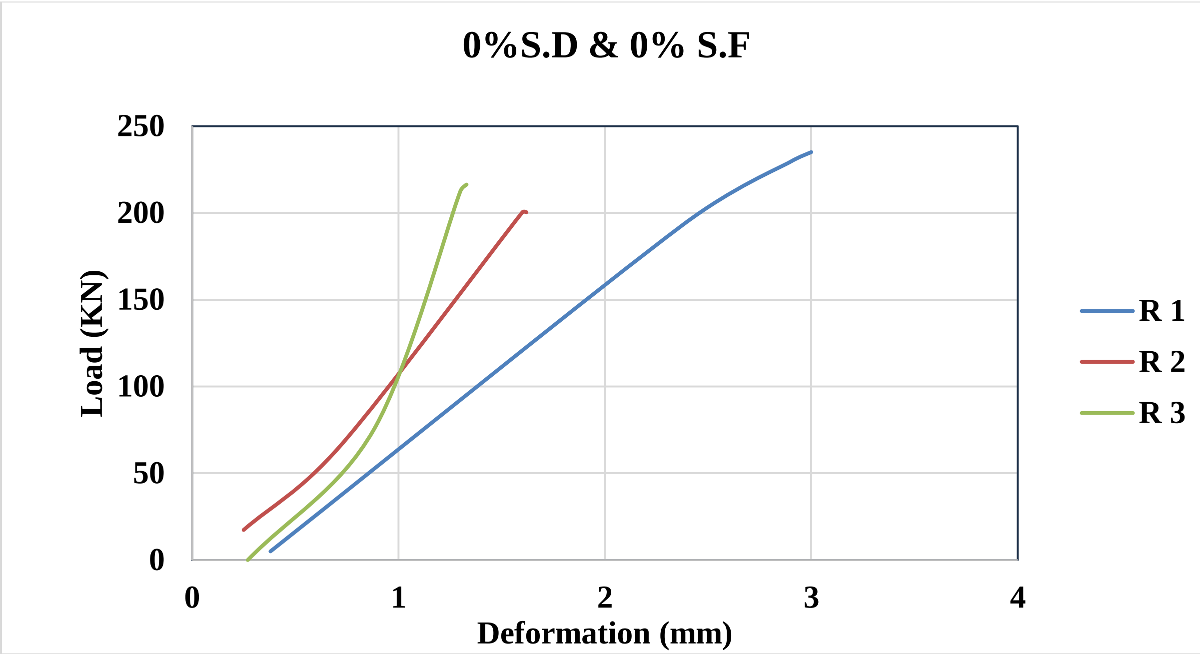


Figure 16: Compressive Strength Curves (0% SD & 0% SF)

4.3 Comparison of Cube Specimen at 3% SD and 0.5% SF

The addition of saw dust increases from 0 % to 3% by the steel fibre is added to 0.5% in this case. The above table indicates that the specimen's maximum load is 215.12 kN in the case of the 3S1 sample. The overall change in the entire load is more significant in this scenario because the other two cubes have low load resistance. If seen from the perspective of the previous testing configuration, the results are inadequate in terms of the load handled by the concrete.

Table 19: Compressive Strength Result (3% SD & 0.5% SF)

Value		3S1	3S 2	3S3
Lower Cracking Point	Ft	0	3.2	3.94
Yielding Point	Fp	28	37.5	192.82
Ultimate Yielding Point	FeH	213.5	206.42	207.4
Fracture Point	fm	215.12	212.44	209.7
Change in Length at Lower Cracking Point	Δt	0.35	0.29	0.28
Change in Length at Yielding Point	Δp	1.6	1.2	1.99
Change in Length at Ultimate Yielding Point	Δeh	2.61	2.52	2.28
Fracture Point	Δm	3.22	2.68	2.32

The following graph indicates the variation between the load and the deformation, which is two elastic compared to the previous case. The more curvature means that the curves have more velocity corresponding to the addition of the steel fibre. The overall behaviour of the 3S1 sample is significant compared to the other two because it shows the maximum achievement of the load and defamation under the elastic limit till fracture.

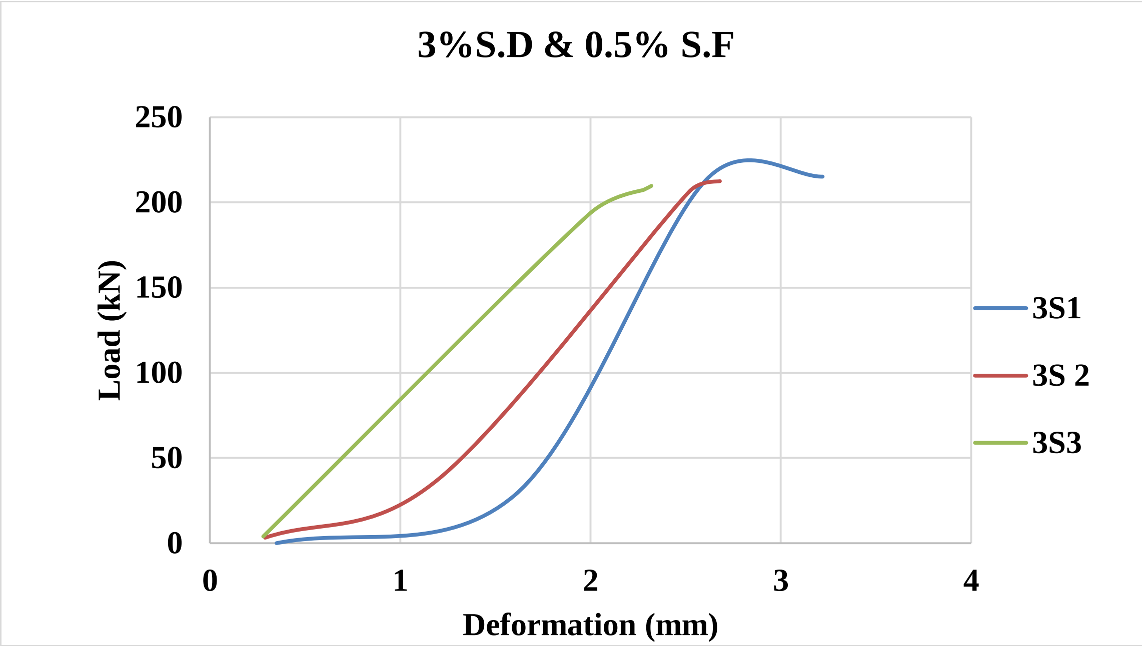


Figure 17: Compressive Strength Curve (3% SD & 0.5% SF)

4.4 Comparison of Cube Specimen at 6% SD and 1% SF

From the following table, it is clear that the maximum load resistance obtained is 212.44 kN. This is in the case of the 6S2 sample, which seems to have a minimum fracture load of 35 kN. The critical behaviour here is that the most significant change in the load handling is observed in the case of 6S3, which indicates has a significant error that can be attributed to the improper handling of the sample.

The following graph shows the behaviour of load and deformation, which clarified that 6S2 simple shows completely unrealistic behaviour compared to the other two. The behaviour of the 6S3 sample can be attributed to being aligned with the standard curve, but the 6S2 sample does the overall load handling.

Table 20: Compressive Strength Result (6% SD & 1% SF)

Value		6S1	6S 2	6S3
Lower Cracking Point	Ft	3	3.2	3.94
Yielding Point	Fp	115.84	35	147.28
Ultimate Yielding Point	FeH	203.4	210.75	186.34
Fracture Point	fm	205.82	212.44	176.87
Change in Length at Lower Cracking Point	Δt	0.25	0.29	0.28
Change in Length at Yielding Point	Δp	2.75	1.67	3.25
Change in Length at Ultimate Yielding Point	Δeh	4.27	2.7	4.25
Fracture Point	Δm	4.5	2.72	5.1

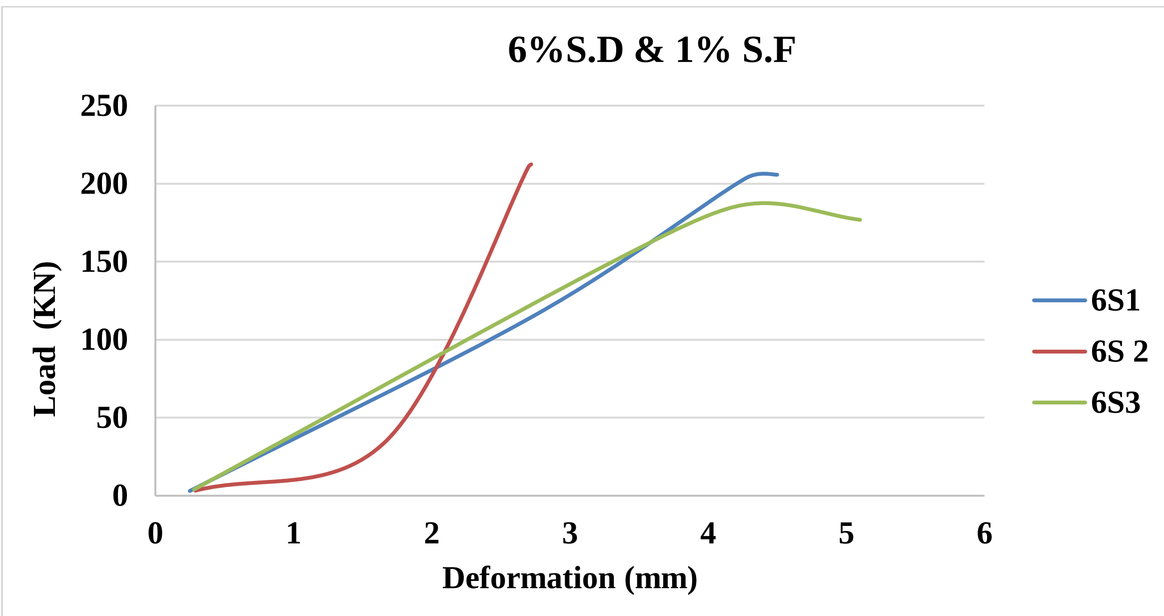


Figure 18: Compressive Strength Test Result (6% SD & 1% SF)

4.5 Comparison of Cube Specimen at 9% SD and 1.5% SF

In the following table, it is clear that the maximum load resistance is obtained to be 83.48 kN in 9S2. The other two samples had low load resistance, which can be attributed to the improper handling of the sample and others wanted in the concrete manufacturing. However, if seen from every perspective, the results are significantly find the reduction in the load resistance when the addition of stardust is increased to 9%.

Table 21: Compressive Strength Result (9% SD & 1.5% SF)

Value		9S1	9S 2	9S3
Lower Cracking Point	Ft	2.4	2.88	2.56
Yielding Point	Fp	50.48	76.88	53.4
Ultimate Yielding Point	FeH	82.6	83.48	82.02
Fracture Point	fm	62.6	60.5	61.24
Change in Length at Lower Cracking Point	Δt	0.3	0.25	0.3
Change in Length at Yielding Point	Δp	1.95	3.5	1.95
Change in Length at Ultimate Yielding Point	Δeh	3.65	4.48	3.7
Fracture Point	Δm	7.21	8.1	7.4

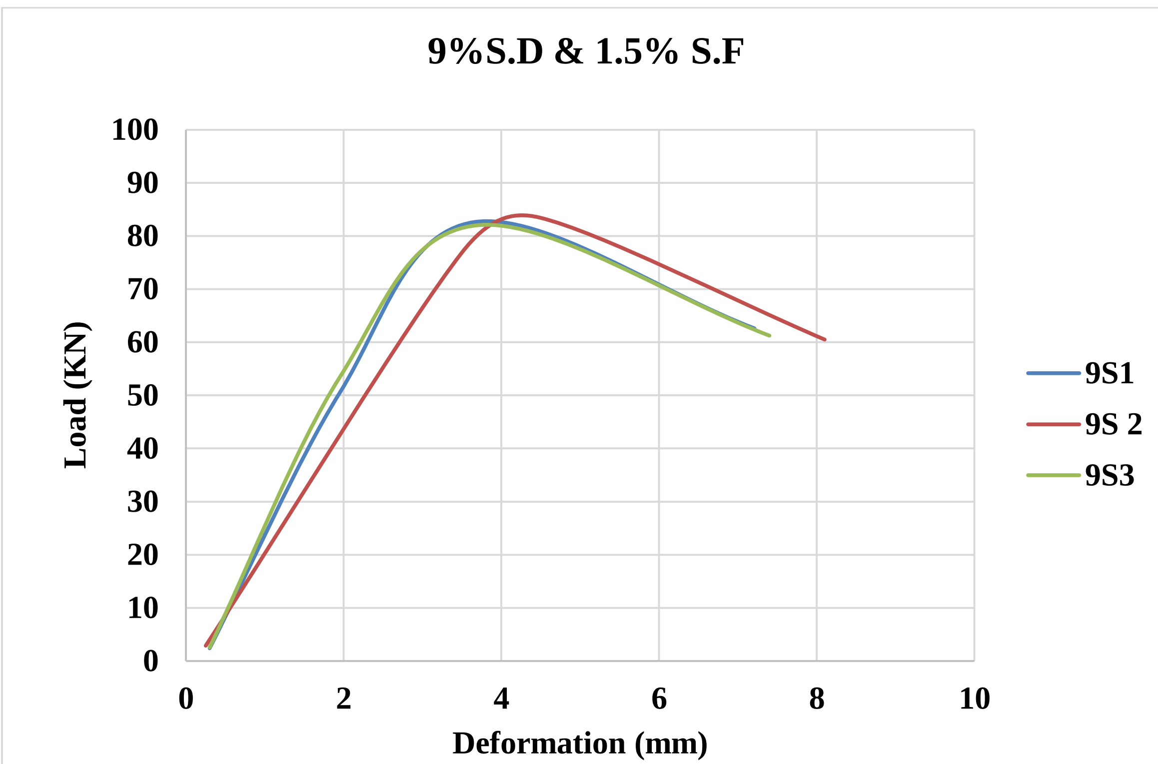


Figure 19: Compressive Strength Curve (9% SD & 1.5% SF)

The above graph shows the compression test results at 9%, according to which the significant elastic behaviour is observed as the addition of the steel fibre is increased by 1.5 %. This type of behaviour is not evident from the previous graphs, but this shows that the steel significantly provides tensile resistance to read while also reduce its ability to handle the compressive loads.

4.6 Comparison of Cube Specimen at 12% SD and 2% SF

By increasing the percentage of sound to 12% of it is evident from the above table that the maximum load resistance is obtained to be 82.02 kN, which is significantly better as compared to the other two samples utilized in the same test. There is a significant variation in the overall strength in terms of the lord as the deformation happens in a completely unpredictable way.

Table 22: Compressive Strength Result (12% SD & 2% SF)

Value		12S1	12S2	12S3
Lower Cracking Point	Ft	2.56	3.04	0
Yielding Point	Fp	53.4	41.94	34.98
Ultimate Yielding Point	FeH	82.02	52.76	55.58
Fracture Point	fm	58.75	28.3	33.67
Change in Length at Lower Cracking Point	Δt	0.35	0.37	0.35
Change in Length at Yielding Point	Δp	1.95	2.2	3.1
Change in Length at Ultimate Yielding Point	Δeh	3.7	4.05	5
Fracture Point	Δm	7.3	8.1	10.2

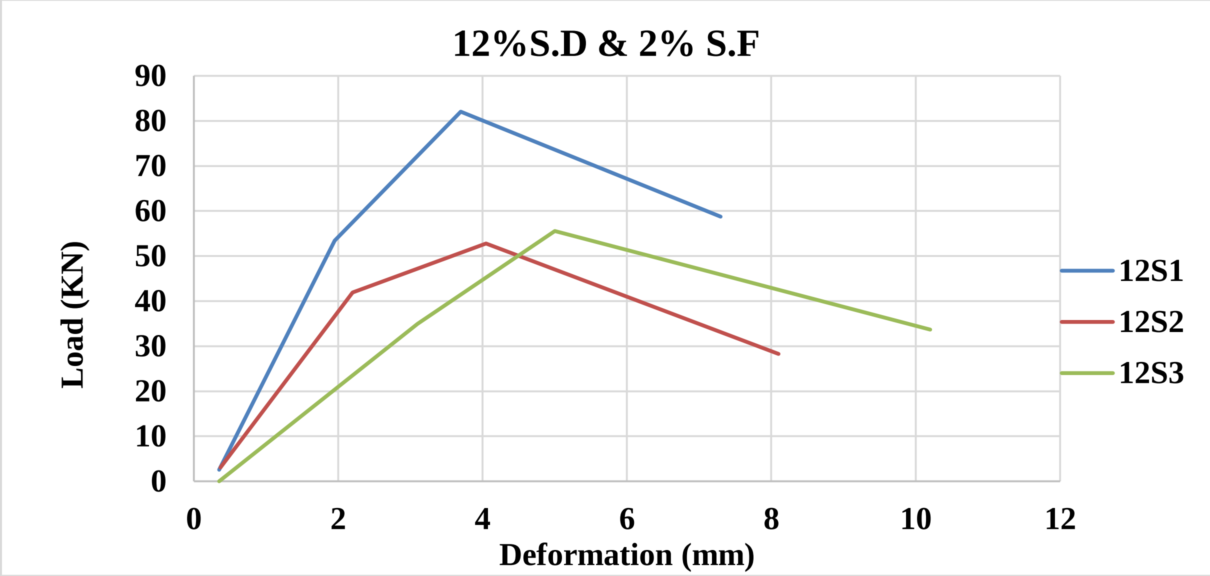


Figure 20: Compressive Strength Curve (12% SD & 2% SF)

The above graph shows that the total elastic behaviour is observed as 2% of steel fibre is introduced in the concrete and 12% sawdust. The overall load and deformation behaviour of the 12S1 sample is adequate from the perspective of the elastic analysis and the expected Load Deformation values. This can be attributed to the battery manufacturing of the concrete and the mixing procedures, which has resulted in the concrete while the addition of the sawdust is 12%.

4.7 Flexure of Beam Specimen at 0% SD and 0% SF

Table 23: Flexure Test (0% SD & 0% SF)

Value	B.R1	B.R2
Ftb	0	0
Fpb	9.42	1.34
Fbb	7.82	1.32
Δt	0	0
Δp	3.5	0.7
Δeh	3.7	0.8

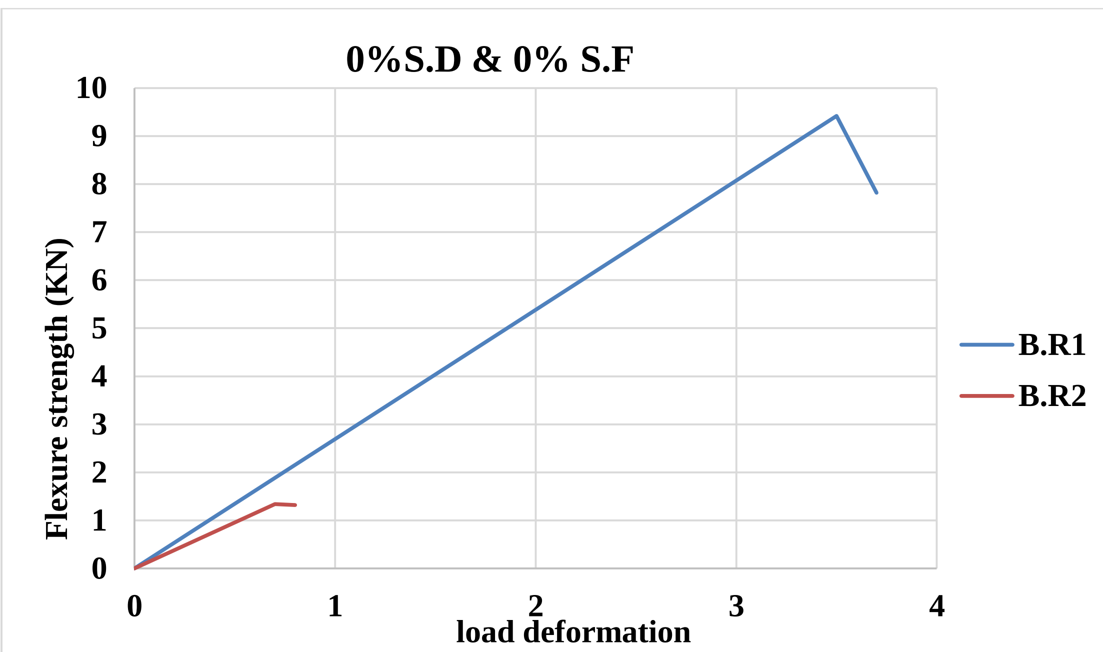


Figure 21: Flexure Strength Test (0% SD & 0% SF)

From the above table, it is clear that the maximum load handled by the beam is 9.42 kN. This is in the case of B.R1 simple world. The second sample has significantly low load handling capacity due to the improper manufacturing of the concrete and errors involved in the experiment. The comparative reduction in the load handling capacity of the beam is due to the improper testing procedure, but the maximum load can be taken to be 9.42 kN.

The above graph shows the comparative difference between the behaviour of the load and deformation. It can be seen that the B.R2 sample has the minimum curve behaviour because of its significant impact due to errors involved in the experiment. However, it is evident that the curves are showing absolute brittle behaviour because the steel fibres are not added.

4.8 Flexure of Beam Specimen at 3% SD and 0.5% SF

The 3B.S2 sample has the maximum flexural load resistance of 10.78 kN. The first sample has minimum load resistance because of the others involved in the experiment and improper handling of the beam when it is placed in the compression testing machine. However, the 10.78 kN is an adequate value from the perspective of the flexural strength of concrete having a 0.5 % of steel fibres.

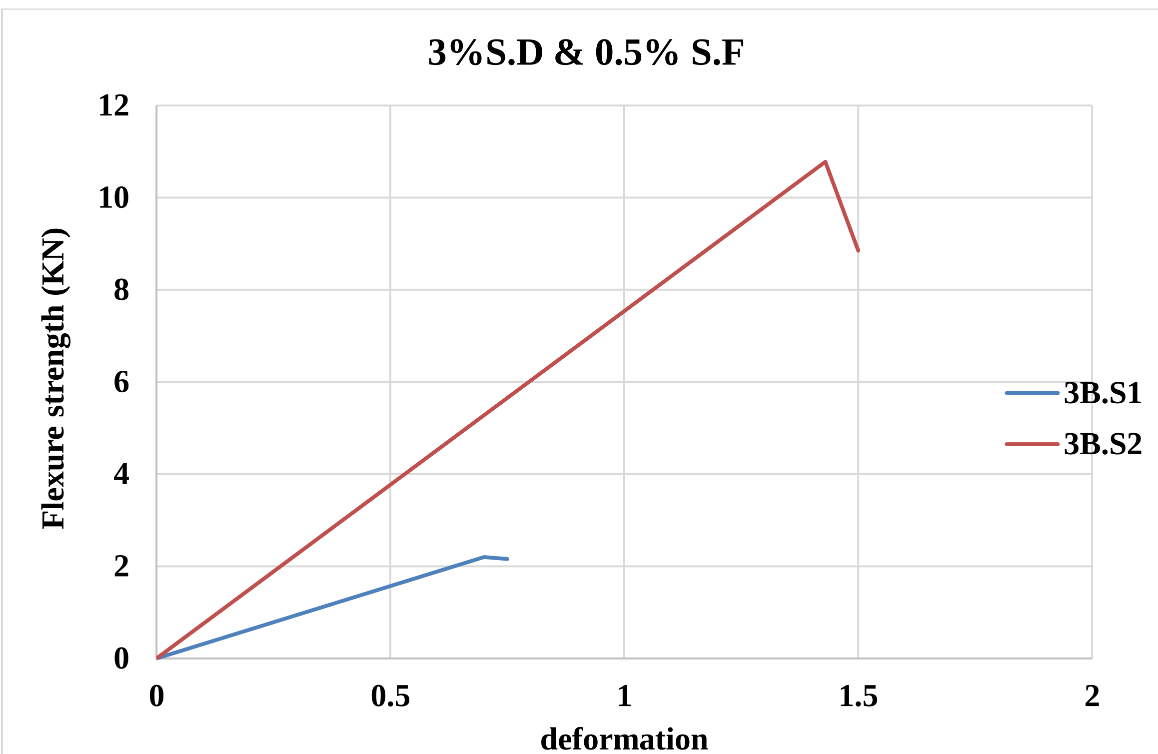


Figure 22: Flexure Strength Test (3% SD & 0.5% SF)

Table 24: Value of Flexure Test (3% SD & 0.5% SF)

Value	3B. S1	3B. S2
Ftb	0	0
Fpb	2.2	10.78
Fbb	2.16	8.85
Δt	0	0
Δp	0.7	1.43
Δeh	0.75	1.5

It is clear from the above graph that the 3% addition of the Sawdust does has significantly made the behaviour of the curve to be slightly elastic, while the presence of the steel fibre has also added to the curvature. The second sample has performed well as compared to the first one, and it also indicates the presence of error in the experiment because both values should be the same as the concrete is made with respect to the same specifications.

4.9 Flexure of Beam Specimen at 6% SD and 1.0% SF

Table 25: Flexure Test (6% SD & 1.0% SF)

Value	6B. S1	6B. S2
Ftb	0	0
Fpb	4.22	3.82
Fbb	3.56	3.48
Δt	0	0
Δp	0.5	0.9
Δeh	0.75	1.1

The experiment shows that there is a significant reduction in the load handling capacity of the beams when the addition of Sawdust is increased to 6%, while the addition of steel fibre is also increased to 1%. Sample 6B.S1 has performed well with the bending load capacity of 4.22 kN. The behaviour of both samples is adequate as the values are close to each other, which indicates that the percentage of error is typically low.

It is evident from the above graph that the experiment has performed well, as the results indicate the better performance of the concrete in both samples. But there is a reduction in the load handling capacity of the beams as a higher percentage of Sawdust is introduced in the experiment. The behaviour is also brittle, as evident from the curve, because there is no significant curvature present which can show that the elastic behaviour is dominated due to the addition of 1% steel fibres.

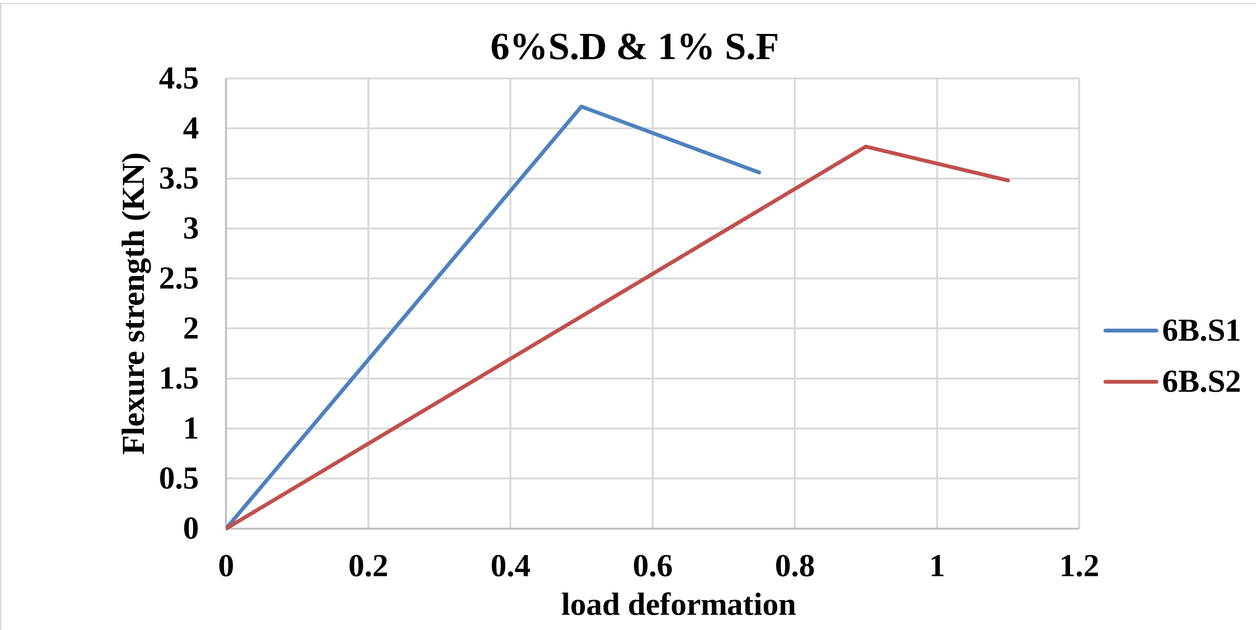


Figure 23: Flexure Strength Test (6% SD & 1.0% SF)

4.10 Flexure of Beam Specimen at 9% SD and 1.5% SF

Table 26: Flexure Test (9% SD & 1.5% SF)

Value	9B. S1	9B. S2
Ftb	0	0
Fpb	5.82	5.78
Fbb	5.68	5.63
Δt	0	0
Δp	1.1	1.03
Δeh	1.17	1.08

At 9% addition of the Sawdust, it is evident that the maximum load handling capacity of the beam is 5.82 kN which is significantly less as compared to the control samples. However, the overall behaviour of the experiment is adequate due to the presence of minimal error because the values are close to each other in the case of both samples.

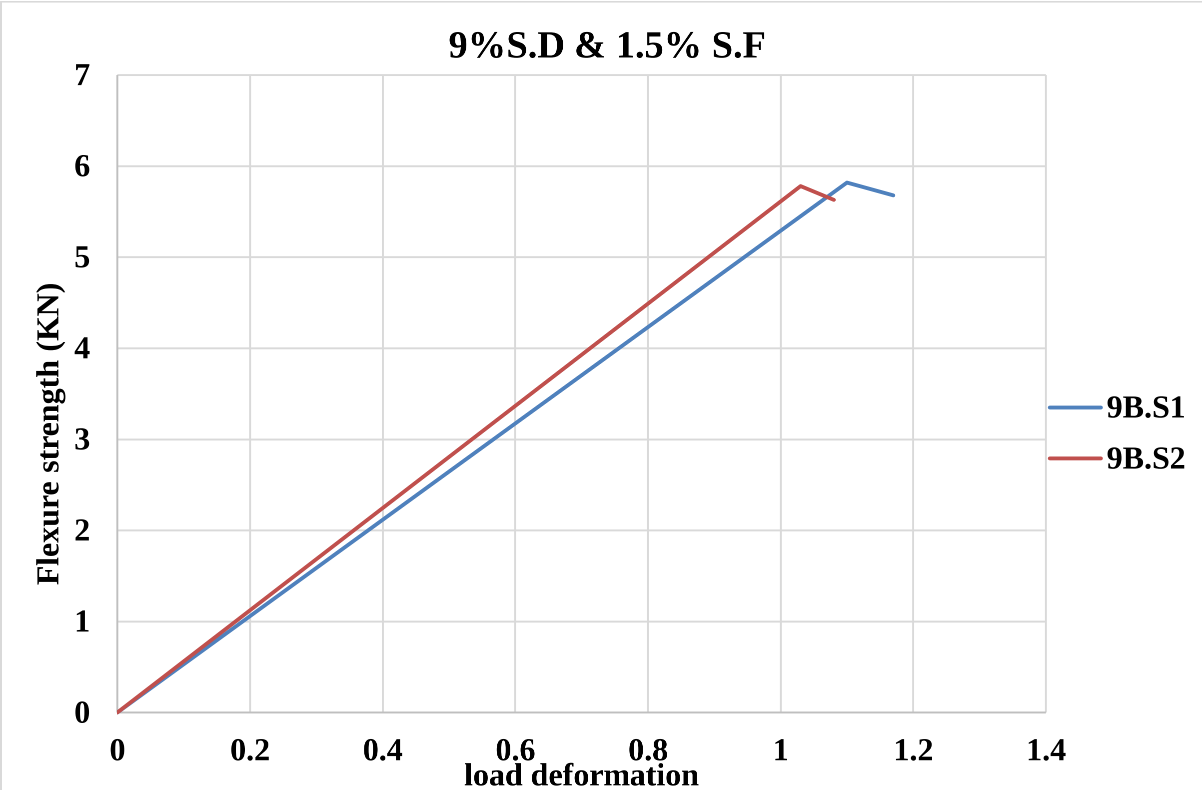


Figure 24: Flexure Strength Test (9% SD & 1.5% SF)

From the above graph, it is evident that the overall behaviour of the beams is very brittle and the results are close to each other, and there is no significant curvature that can show that the behaviour is elastic. The higher percentage of steel fibre should have provided significant bending strength to the beam because it is very beneficial for increasing the elastic stress in the beams, but it should be noted that the load-carrying capacity can be attributed to the accurate results due to the errors in the experiment.

4.11 Flexure of Beam Specimen at 12% SD and 2% SF

Table 27: Flexure Test (12% SD & 2% SF)

Value	12B.S1	12B.S2
Ftb	0	0
Fpb	5.98	8.94
Fbb	5.44	8.26
Δt	0	0
Δp	1.8	1.9
Δeh	1.83	1.95

From the above table, it is evident that sample 12B.S2 performs well as compared to the first sample because it has got a high load-carrying capacity of 8.94 kN. That is simple, but it is not significant enough to be said that the results are not error-free. The errors are present in the first sample results because it is significant as compared to the expected results in case of the 12% replacement of the Sawdust.

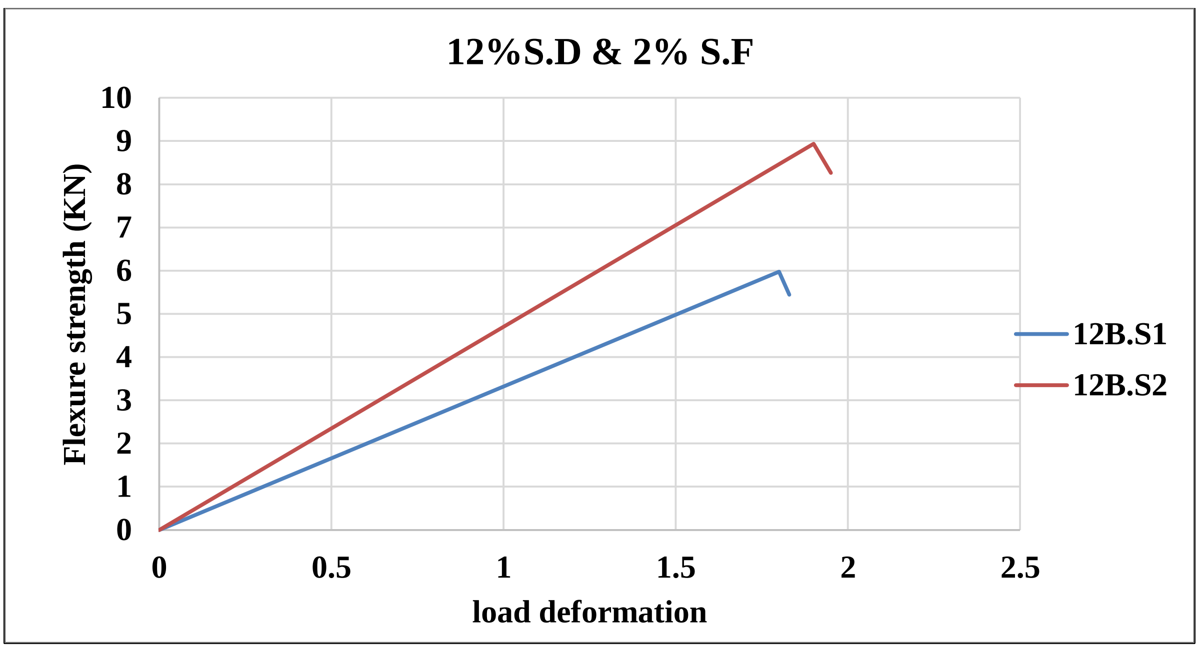


Figure 25: Flexure Strength Test (12% SD & 2% SF)

From the above graph, it is clear that the samples are allowed to each other because they have provided the egg rate is found in relation to the flexural load carrying capacity. There is strong evidence that the deformation by the load is typically very sudden in the case of the samples because it is aligned with the experimental procedure and the requirements of the flexural strength.

4.12 Tests Performed

4.12.1 Compression Test

Compressive strength of the solid examples (150mm x 150mm x 150mm) was resolved by the TS EN 12390-3. The disappointment load was recorded. The compressive strength of the example was determined by isolating the disappointment load by the cross-sectional space of the example. Compressive strength of the 3D squares was resolved at restoring times of 28 days.

4.12.2 Compression Test Results

Following figure show the compressive strength for 6% saw dust with 1% steel fibres at of 28 days strength is increased as compare to reference and other specimen like (3% SD 1% SF,9%SD 1.5% SF and 12%SD 2% SF). Hence, we observer After adding 6% saw dust 1% steel fibre the compressive strength is increased 10.56%.

Table 28: Compressive Test Result

	0% SD & 0% SF	3% SD & 0.5% SF	6% SD & 1% SF	9% SD & 1.5% SF	12% SD & 2% SF
Peak value (KN)	229.5	235	253.75	170.3	165
stress (MPa)	10.2	10.44	11.27	7.56	7.33
Strain (mm/mm)	0.0193	0.02	0.021	0.0146	0.013

4.12.3 Tensile Strength

The split rigidity of cylindrical shaped examples was resolved according to ASTM C496. Split elasticity was resolved at relieving times of 7 days and 28 days. The cylindrical shaped examples were 200 mm in tallness and 100 mm in measurement. The split rigidity (T) was resolved from the equation.

4.12.4 Results of Split Tensile Strength

Steel fibres show high tensile strength resistance as compared to concrete. In case of split tensile strength for 6% SD and 1% SF at 28 days tensile strength is increased as compare to reference and other specimen like (3% SD 1% SF, 9% SD 1.5% SF and 12% SD 2% SF). Hence, we observe after adding 6% saw dust 1% steel fibre the tensile strength is increased 12.88%. When the adding of 9% SD and 1.5% SF the tensile strength is reduce due to high percentage of saw dust. Although the quantity of steel fibre is more from previous specimen therefore, we have excessive amount of steel fibre but cannot add more due to less cohesiveness of saw dust. Which does not allow split tensile strength to increase.

Table 29: Split Tensile Test Result

	0% SD & 0% SF	3% SD & 0.5% SF	6% SD & 1.0% SF	9% SD & 1.5% SF	12% SD & 2.0% SF
Peak Tensile Strength	2.25	2.36	2.54	1.73	1.4

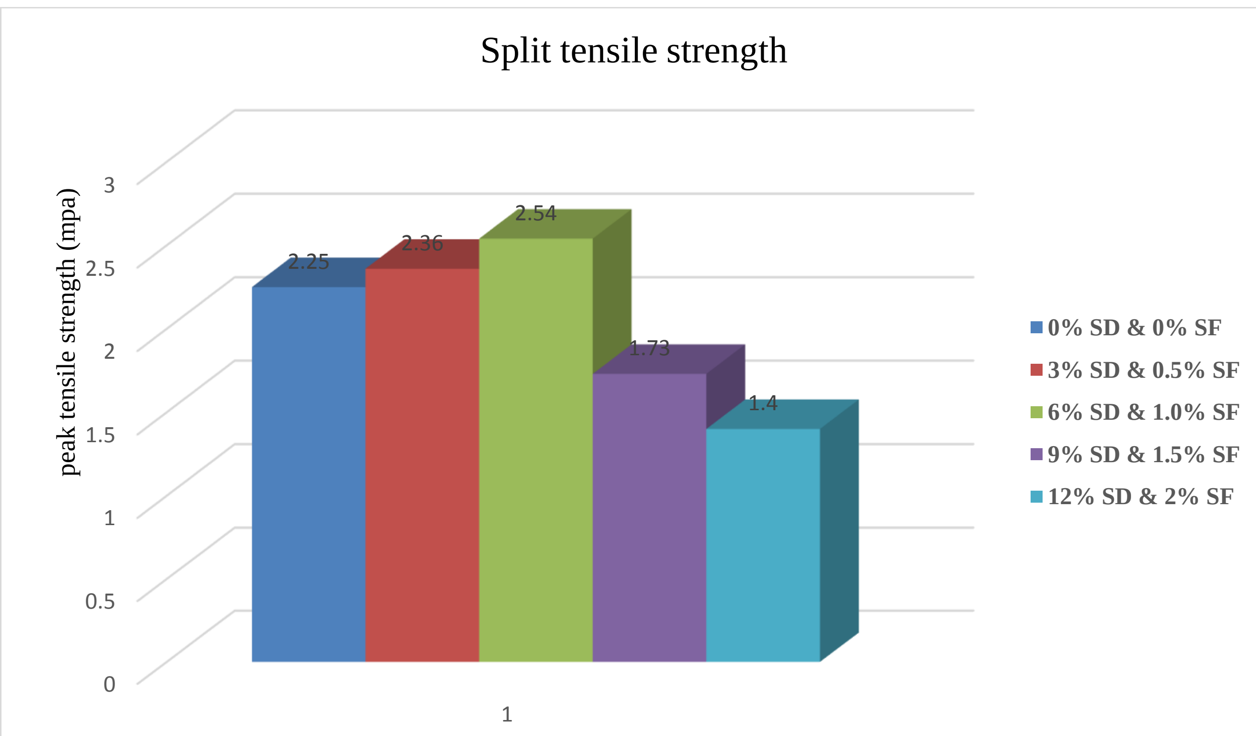


Figure 26: Comparative Study Graph of Split Tensile Strength

4.13 Flexural Strength

Flexural strength of the concrete prisms was determined as per ASTM C293. The dimensions of the beam were 612 mm x 135 mm x 135 mm. Flexural strength was determined for the curing periods of 28 days.

4.13.1 Results of Flexural Strength Test

Steel fibres show high flexure strength resistance as compared to concrete. In case of split flexure strength for 3% SD and 0.5% SF at 28 days flexure strength is increased as compare to reference and other specimen like (6% SD 1% SF,9%SD 1.5% SF and 12%SD 2% SF). Hence, we observe after adding 3% saw dust 0.5% steel fibre the flexure strength is increased 14.43%. When the adding of 6% SD and 1% SF the flexure strength is reduce due to high percentage of saw dust.

Table 30: Flexure Test Comparative Results

	0% SD & 0% SF	3% SD & 0.5% SF	6% SD & 1.0% SF	9% SD & 1.5% SF	12% SD & 2.0% SF
Compression Strength	9.42	10.78	4.22	4.15	4.1
Flexural Strength	1.675	1.916	0.750	0.738	0.729

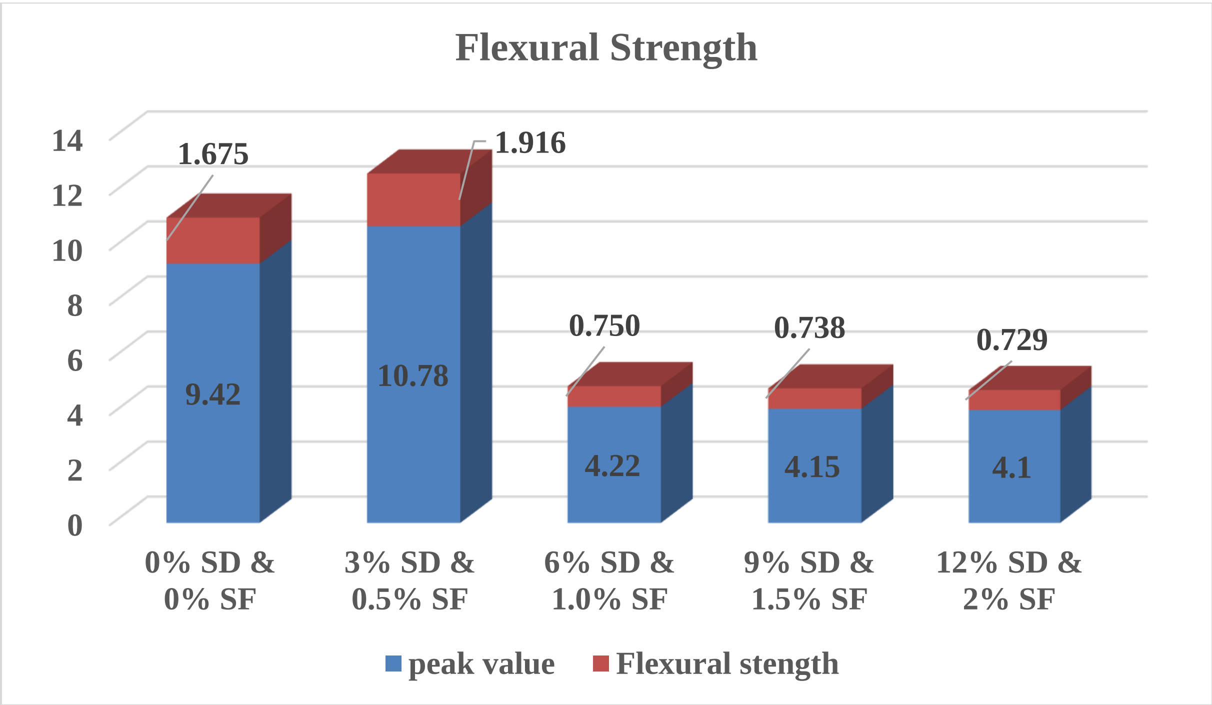


Figure 27: Comparative Study Graph of Flexure Strength

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

The research on mechanical properties of sustainable light weight steel fiber reinforced concrete (SFRC) incorporating wood waste as cement replacement under compression load on cube, split tensile load test on cylinder and flexure on prism and comparison that can be made between referenced specimen and replacement with SD and SF specimen. Different findings of this research work are discussed below.

- The results obtained from the experimental investigation show a significant impact of digitalization of Steel fiber and sawdust on the behavior of the concrete. When the quantity of sawdust is increased in the concrete that results in a significant decrease in the compressive strength is not adequate for architectural sustainability.
- However, it is proved from the research that the utilization of the sawdust can provide a significant reduction in the cost of manufacturing the concrete that can be effectively used for the low profile applications.
- By effective utilization of the Steel fibers in the concrete, it is observed that the maximum increment in the compressive strength can happen around 7-10%, which is a significant value from the perspective of maintaining better applications of the concrete. Compressive strength at 6% saw dust with 1% steel fibers at 28 days strength is increased 10.56 %.
- The Steel fiber also impacts the workability of the concrete because it decreases as the quantity of the Steel fiber is increased.
- The impact on the flexural strength of the concrete is also evident from the experimentation as the Steel fiber provide rigidity to the concrete, which contributes to making the overall change in the concrete effective. At 3% SD and 0.5% SF at 28 days flexure strength is increased 14.43% as compare to reference
- It was observed that the high percentage of saw dust does not contribute to increasing the concrete's mechanical properties.

- In case of split tensile test, maximum strength values are observed for 1% steel fibers for 6 % saw dust. The strength is increased 12.88 as compare to reference.

5.2 Recommendations

Based on the results, it is recommended that the sawdust be available in large quantities because the applications in concrete manufacturing are high, and it can provide lightweight concrete according to the required level of application. The material is recyclable, but its applications in the concrete are not robust because it reduces the mechanical properties if used in a higher percentage. Therefore, it is recommended to always use the minimum rate of the sawdust to achieve a slight deviation in the weight of the concrete. Consequently, it is recommended that the 3% is the optimal limit of the sawdust, which must be added into the concrete to achieve a substantial reduction in the weight. Furthermore, the percentage of Steel fiber must be kept at 0.5 per cent because the higher quantities make the concrete more brittle, which is not desirable in any case. Adequate spacing must be provided between the formwork and the concrete because tension due to the additives can cause significant damage to the formwork. Therefore, it needs to be controlled.

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