

Fibre Reinforced Concrete from Industrial Waste- A Review

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ABSTRACT: With increasing generation of industrial waste, waste utilisation can save us money and is claimed to be of great utility by researchers when added to concrete in form of fibres. We can use metallic fibres and waste PP, PET, HDPE fibres as reinforcement of normal concrete. We know that, both the products are available in abundance and at a cheaper cost, we can access effects of the incorporation of waste metallic fibres (WMF) and polypropylene fibres (WPF) on the fresh and hardened concrete properties. Numbers of experiments have been performed to see the performance of FRC in compression, tension, shear, flexure in extreme environments etc. Detailed review has been given in this paper about the different experimentation techniques, parameters and results, which have generally shown that, addition of fibres shows an improvement in its physical properties and enhances durability. The fibres essentially arrest any advancing cracks by applying pinching forces at the cracks tips, thus delaying their propagation across the matrix. Hence proliferation of WFRC is sustainable, economical and provides a better design. The results obtained also show short fibres arranged in random fashion provide better strength to FRC in contrast to long fibres which tend to decrease the compressive strength.. However, adding the hybrid fibres increases the flexural strength of the WFRC. It has been observed that the composites reinforced with the WPF is more advantageous in terms of post-cracking behaviour and load-carrying capacity as compared to the composites reinforced with the WMF even in some cases.

KEYWORDS: Fibre reinforced concrete, waste metal fibres, waste plastic fibres, mechanical properties.

I.INTRODUCTION

Concrete is most frequently used man made material in the world. It is durable, inexpensive, and readily mouldable into complicated shapes and has good compressive strength and stiffness. However it has low tensile strength, low ductility and low energy absorption. Due to its lack of tensile strength, it is reinforced with reinforcement bars or mesh (rebar's) in structures (carrying traffic load, spanning a void or bearing another structure such as a wall).But this kind of reinforcement is crude and ineffective for crack control. Also this reinforcement gets decayed and corroded in abusive environments. Concrete technology now includes reinforcement in the form of polymeric fibres, steel or glass fibres. Fibre-reinforcement is not used for structural strengthening, rather it reduces the requirement of amount of rebar's or mesh and adds to the improvement of durability by delaying the crack propagation. The available steel fibres of different categories in market are considerably expensive. But, the steel scraps produced in local lathes and workshops and polypropylene waste can be utilised in form of fibres directly rather than recycling them for other purposes, which can be expensive. The present investigation is carried out to study the effect of steel scrap, galvanised iron, polypropylene fibres obtained from industrial waste on various parameters of concrete, so as to produce fibre reinforced concrete.

The waste metal or polypropylene fibre reinforced concrete can be denoted as M20F30. Where M denotes mix and 20 is its characteristic compressive strength after 28days. Whereas, F refers to fibres and 30 is the length of the fibres added to the concrete mix. It has been established that the addition of randomly distributed metal or polypropylene fibres to brittle cement based materials can increase their fracture toughness, ductility and impact resistance. Since fibres can be premixed in a conventional manner, the concept of fibre concrete has added an extra dimension to concrete construction.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

The problem with addition of fibres is that they decrease the water cement ratio, thus decreasing the workability of mix. We can water reducing super plasticizers instead of adding water to it. Another option is processing of FRC by spray suction de watering technique, in which excess water is drained out to achieve desired water cement ratio. Disposal of plastic has been of great environmental concern and has been growing globally over decades. This waste disposed can be used in FRC. Types of recycled plastic:

- 1) Virgin polypropylene: They are usually 19mm and in slender fibre form.
- 2) Recycled(melted processed) : They are drawn from automobile bumper plastic and are usually 28mm long as slender fibres.
- 3) Recycled(automobile shredded residue) : It contains some rubber along with plastic and are 18 mm long in form of flakes.
- 4) Recycled(shredded): It is obtained by shredding all types of plastics and is usually in flaky form with 25mm planar dimension.

Its use enables effective utilization of intrinsic tensile and flexural strength of the material along with significant reduction of plastic shrinkage cracking and minimizing of thermal cracking. Polypropylene(PP) and Polyethylene terephthalate(PET) are most commonly used as their recycling is more economical and easier than the other types of plastics. Tu L and Kruger D [1]presented new chemical surface modification process "Oxyfluorination" which enhanced the interfacial bond between the surface of fibres and concrete. This process is out of our context but is suggested to enhance properties of waste fibre reinforced concrete.

II.FABRICATION TECHNIQUES

If we use conventional techniques for generating fibre reinforced concrete, the volume of fibre being incorporated into the cement is limited by the capacity of the fibres to be mixed uniformly into the matrix and thus clumping occurs. The conventional methods of mixing include transit truck mixing, mixer drum etc. Clumping may also occur due to the following reasons:

1. Addition of fibres before adding any other component in mixer.
2. Fibre may already be clumped before adding into the mix.
3. Too high volume of fibres may be added.
4. The mixer itself may be inefficient.

Therefore, Fabrication techniques involving mixing fibre with the matrix at initially high water contents and then using dewatering procedures are effective and are most generally used in day to day life. Polypropylene fibres can be added to the concrete in various ways and by using different techniques. The fibres may be incorporated into concrete as short discrete chopped fibres, as a continuous network of fibrillated film, or as a woven mesh. The method of fabrication depends upon the form in which the fibres are available in and the volume of percentage of fibres obtained in each respective technique and method. It is published that concrete panels are reinforced with chopped mono-filament polypropylene fiber by a 'spray suction de- watering' method, in which 6% of the volume is attained. And upto 11% volume is achieved when mono filaments or chopped fibrillated polypropylene films are incorporated into composites.

III.RESEARCH FINDINGS

1) Fresh concrete properties:

- i. **Air content:** Experiment with waste fibrillated polypropylene fibres was conducted by Bayasi and Zeng [4]in 1993.7 mixtures of various lengths and proportions of fibres were made and the results suggest that air content is proportional to the amount and length of fibres. Especially when volume of fibres exceeded 0.3% increase in air content was significant and before that it was equal to or less than that in control beam. Conversely,

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(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

investigation by Soroushian et al(2003)[5] suggest that addition of recycled PP fibres reduces the air content in concrete. It can be ferreted that such use of PP fibres may enhance air entrainment properties of concrete and promote its use in marine constructions.

- ii. **Workability:** This paper reviews slump test (ASTM C 143-78) and inverted slump test (ASTM C-995). Both these tests are helpful in determining the workability of fresh concrete, where inverted slump test is specifically used in case of fibre reinforced concrete. Bayasi and zeng[4] conducted slump and inverted slump cone tests, to check the effects of addition of polypropylene on concrete. Their results state that inverted slump cone time increased, thus it can be inferred that air entrainment becomes difficult and hence its use in corrosion prone structures should be avoided. Another result yields that fibre volume up to 0.3%, has significant effect on fresh mix workability but it deteriorates as the fibre volume increases. In fact increase in inverted slump cone time was critically affected by 19mm (long fibres) than 12.7mm(short fibres) in the experiment. Soroushian et al performed experiments to see effect of WPP fibres, which are considered as macro fibres, and found that viscosity of concrete increases due to large surface area of fibres and their ability to absorb cement paste. Mazaheripour H et al[9] suggested to limit the fibre volume to 0.1-1% and add super plasticizers to improve workability.

2) Hardened concrete properties:

- i. **Compressive strength:** Experiments were conducted by Mohammed Seddik Meddah , Mohamed Bencheikh[3], where waste fibres of metal and polypropylene were taken and tested as given in [3]. The results show that the addition of short fibres(<30mm) result in decrease of compressive strength and that of long fibres shows no change in compressive strength. Also addition of metal fibres shows no change in compression strength. Since addition of fibres increases pore volume, it can be inferred that high fibre volume lead to high porosity and hence decrease in compressive strength. Since the fibres used are waste and therefore its shape and geometry cannot be relied upon due to which the discrepancies in strengths are seen, while fibre geometry plays a major role in determining the strength. Unit weight is another aspect which dictates the better compressive strength in WMFRC rather than WPFRC. It was identified that multimodal composites gave the best compressive strength. Further amount of coarse aggregate is decreased which is the main contributor of passive compressive strength, and an increase in fine aggregate content in the experiment further reduced the compressive strength. Bayasi and Zeng[4], performed experiments by adding fibrillated waste polypropylene fibres to the concrete and included results of compressive strain at peak stress and compressive toughness index. Compressive toughness index(CTI) is :

$$CTI = \frac{\text{Total compressive energy absorbed}}{\text{pre peak compressive energy absorbed}}$$

It is concluded that long PP fibres(19mm) reduce compressive strength but increase energy absorption capacity and toughness characteristics. Therefore usage of long fibres increases CTI. Whereas, using short fibres increase compressive strength till the volume of fibres used is less than 0.3%.

According to Soroushian et al.[5], Inducing slender recycled plastic fibre increases the compressive strength of FRC, but addition of non slender fibres may cause a small loss in compressive strength. This reduction in compressive strength due to non slender fibres may be accounted to their low elastic modulus.

G.Murali et al(2012)[7] investigated properties of FRC with waste metal fibres from - soft drink bottle caps, beverage tins, steel powder, mild steel lathe waste. Results of this experiments show that compressive strength is highest for FRC with steel powder, 41.25% higher than the conventional (without fibres). Ashish et al [19] performed experiments using waste metal fibre in M20, and reported that even though compressive strength increases for 7 days curing period it decreases over 28 days as compared to the control specimen without fibres.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

Mixture code	Compressive strength (MPa)	Flexural strength (MPa)
OPC	30	8.1
WMF6/1.0	31	6.7
WMF6/1.25	29.5	7.7
WMF6/1.5	30	6.4
WMF3/2.0	29	6.7
WMF3/2.5	27	6.5
WMF3/3.0	24.5	6.9
SF3/3.0	30.5	7.9
WPF6/0.5	29	8.1
WPF6/0.75	25.6	7.8
WPF6/1.0	21.5	8.1
WPF5/0.5	29.5	6.5
WPF5/0.75	26	8.1
WPF5/1.0	25	8.8
WPF3/0.5	23.5	4.5
WPF3/0.75	21	6.0
WPF3/1.0	20	6.4
MF6/1 + MF3/2	29.2	10.8
MF6/0.75 + PF5/0.75	24	9.5

Mixture code	Unit weight (kg/m ³)
OPC	2387
WMF6/1.0	2441
WMF6/1.25	2437
WMF6/1.5	2395
WMF3/2.0	2445
WMF3/2.5	2442
WMF3/3.0	2437
SF 1.5/3.0	2460
WPF6/0.5	2364
WPF6/0.75	2318
WPF6/1.0	2291
WPF5/0.5	2355
WPF5/0.75	2304
WPF5/1.0	2298
WPF3/0.5	2367
WPF3/0.75	2316
WPF3/1.0	2296
MF6/1 + MF3/2	2453
MF6/0.75 + PF5/0.75	2328
PF6/0.4 + PF5/0.6 + PF3/0.4	2307

- ii. **Flexural behaviour:** This test indirectly measures the tensile ability of concrete and how a concrete beam resists failure in bending. According to the experimental results by Mohammed Seddik Meddah, Mohamed Bencheikh [3], addition of short or long fibres of waste metal and PP does not improve the flexural strength. But from the values we can see that a mixture of short and long fibres has enhanced the flexural strength greatly as compared to the control specimen. The author suggests the use of multi modal fibres rather than mono fibre system. Fibre volume and length also effect flexural performance and post cracking behaviour. This experiment suggests that volume of fibres added is proportional to the ductility in WMFRC, but experimentally 1% was possible. For the same amount and lengths of metal fibres added to FRC as in PP, results show that WPFRC yields better flexural strength and ductility as compared to WMFRC. The post cracking behaviour analysis according to this suggests that mono fibre system does not affect this property as such. But addition of both short and long fibres tends to improve the crack initiation resistance (done by short fibre) and crack localization- taking forces out of macro cracks(done by long fibres). And, it is seen that addition of WPF produce quasi ductile FRC rather than WMF. Experiment by S.Aravindan and C.D.Arunkumar[6] on FRC from industrial waste as described in the concerned paper. The flexural strength for M20 grade concrete was found to be highest (~2times of control beam) with 1% galvanised wire, and 2% lathe scrap. Waste metal fibre reinforcement should a great amount of increase in flexural strength till 3% volume. Whereas, Oliveira[11] suggests that there is no such effect of fibres on flexural properties, but it is more dependent on cement matrix properties , and Soroushian et al [5] fortified that waste (macro sized) PP fibres enhance post cracking ductility and flexural toughness.
- iii. **Durability:** Durability is the most important factor of concrete, and this paper aims to review durable and sustainable concrete. Brown et al[13] studied the effects of virgin PP fibres in reactive environment and results showed that these fibres did not show any reduction in tensile properties even when exposed to salt water conditions at various temperatures ranging from 70°C to -7°C for six months. Won et al [15] recorded that recycled PET FRC had excellent resistance to salts, CaCl₂ and sodium sulphate. Experiments by Ochi at al[14] and ACI 544 [18] report that recycled PET fibres are also resistant to alkali environment. Fraternali et al [16] performed experiment with Pet fibres from post-consumer plastic bottle in the same manner as Ochi et al[14] and found that tensile strength was 87% after the attack. This implies that waste PET fibres have good alkali and sulphide resistance. Silva et al[18] performed experiment s wit PET fibres in Lawrence solution, which simulates cement matrix environment for 150 days at room temperature, and it resulted in degradation of surface of fibres, and thus reduction in toughness.
- iv. **Permeability:** Permeability of concrete is a major contributor to its durability. Mohammed Seddik Meddah , Mohamed Bencheikh[3], suggested that more the fibre length and characteristics, more air voids will be formed.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

WPF induces more void spaces in the total volume than the WMF, due to the high surface area of PF than MF. This increase in porosity tends to increase permeability also. Thus, subverting its usage in marine construction. Experiments by Bayasi and Zeng[4] investigate the effect of waste fibrillated PP fibres of lengths 19mm and 12.7mm, where 19mm showed an increase in permeability and no effect on permeable voids. In contrast, 12.7mm long fibres denote a slight increase in permeability and decrease in volume of permeable voids.

- v. **Toughness and Impact resistance:** Considering the experiment conducted by Mohammed SeddikMeddah , Mohamed Bencheikh[3], we find that the Toughness of FRC is considered as its ability to absorb energy across the crack and is found in this experiment by using area under load displacement curve. By finding toughness indices, it was concluded that WPF provided more toughness than MF. One more possible reason for poor performance of MF may be their random orientation and geometry(since they were directly used as waste itself). Impact resistance is said to be increased with addition of fibres. According to Bayasi and Zeng[4], Impact resistance significantly improves with addition of short fibres than long fibres till the volume of fibres added does not affect workability of FRC. Similarly Soroushian[5] investigated the effects of adding recycled fibres and suggested that there was a sheer increase in impact resistance of FRC for discrete reinforcement distribution. S.Aravindam[6] suggests that there is a 23.7% increase in impact resistance as recorded by falling weight method. Soroushian et al[5] conducted experiments on abrasion resistance according to ASTM C779 and found that most discrete systems of reinforcement had least abrasion resistance(more mass loss).This was explained by the fact that fibres near surface debonded in abrasion thus also causing changes in bleeding characteristics of FRC from waste polypropylene.

IV.SUMMARY

Usage of industrial waste in fibre reinforced concrete has become a lucrative option to industry, as it is sustainable and durable. This paper covers current state of usage of industrial waste fibres and focuses on waste metal and waste plastic fibres. This paper covers effect of addition of fibres and their volume on mechanical properties on fresh and hardened concrete according to various experiments, given as:

- I. There is an increase in air content due to addition of waste plastic fibres, due to surface unevenness and their load history. Whereas, recycled PP fibres reduce air content in FRC, and may be used in the use of structures in marine environment. It can be implied that air content will increase even more for the addition of waste metal fibres, due to their highly crimped structure. An optimum volume of 3% of fibres is considered not to have adverse effect on air content, and higher amount than this is avoidable.
- II. It is observed that the workability of FRC decreases as the volume of PP fibres increases, especially when more volume is more than 1%. This is due to the large surface area of uneven waste fibres, absorbing cement paste and making the matrix more viscous. The decrease in workability is seen more due to the addition of long fibres. So, short fibres should be added for better workability otherwise super plasticizers can be added.
- III. One of the main factors affecting the compressive strength is unit weight of the mix; FRC from waste metal fibre performs better than waste plastic fibres. Experiments suggest that there is almost a 41.25% increase in the compressive strength when waste metal fibres are used. Using long PP fibres reduces the compressive strength but improves its CTI and toughness characteristics, unlike short fibres which increase compressive performance up to 0.3% and then start to affect it adversely. Also, it was seen that slender fibres should be preferred over non slender fibres from the waste accumulated so that a better performance is obtained in compression, as these fibres do not create void spaces.
- IV. The addition of fibres usually doesn't enhance flexural strength of concrete, but long fibres contribute to quasi ductile behaviour during post cracking period. Rather multi modal fibre composite system contribute to improvement in crack initiation and crack controlling phenomenon's.
- V. Durability of FRC with addition of plastic fibres results in a good resistance to salts, alkaline environment in various extreme temperatures and conditions. Whereas metal fibres are highly susceptible to corrosion and hence PP and PET fibres should be encouraged for utility in marine construction, specially rip raps etc.
- VI. Longer fibres and better fibre characteristics would tend to increase the permeability of FRC. PP fibres have higher tendency to increase permeability due to their higher surface area rather than metal fibres. In case PP

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

fibres are used, short fibres should be preferred as they showed a decrease in permeability voids in experiments. It is good to avoid usage of PP fibres where impermeability is one of the most important factors of construction. Eg. Water tanks, swimming pools and so on.

- VII. Impact resistance of FRC is proportional to the amount of fibres added, until they do not affect workability of the fresh mix. WMF are not effective in improving the impact resistance because of their random orientation, as compared to WPF. Moreover short fibres of PP perform better over long fibres according to experiments, and discrete reinforcements yield best results for impact resistance and abrasion resistance. It should be kept in mind that WMF should not be used where impact and abrasion resistance are required.
- VIII. Oxyflourination surface treatment of PP fibres would help in reduction of air content, permeability leading to better bonding between fibres and cement matrix and thus improvement in compressive strength and abrasion resistance. This can also ensure its usage in marine constructions and constructions where abrasion resistance is required along with compressive strength.
- IX. Using FRC from industrial waste products would have following benefits:
- More use of recycled steel, post-consumer plastic and metal waste
 - Reduction in slab thickness upto 30%
 - Ideal for joint free design
 - Reduce plastic disposal problem
 - Sustainable, durable and economical
- X. The mechanical strength comparisons for addition of PP fibres are given as below according to various experiments:
- The addition of polypropylene fibers at low values actually increases the 28 days compressive strength but when the volumes get higher than the compressive strength decreases from original by 3 to 5%.
 - The tensile strength increases about 65%~70% of its original upto 0.40% of fibres volume after which it begins to decrease. It increases as the length of the fibre being added to the concrete increases.
 - There is about 80% increase in flexure strength by adding 0.20% fibers in concrete after which strength starts reducing with further increment in fibre volume
 - The shear capacity of concrete increases when fibers are added because of the utilisation of fibres intrinsic properties of high tensile strength and flexibility. There is a remarkable increase in load carrying capacity upto first crack appears.
 - The shrinkage cracking is reduced by 83 to 85% by addition of fibers upto 0.35% and 0.50 %. The more the fibre volume is increased, after 0.5% the improvement in cracking ability starts deteriorating.
- XI. The mechanical properties for the addition of metal fibres as a waste to produce FRC are given as below:
- Addition of polypropylene fibers at values from 0.18% to 0.40% increases the 28 days compressive strength by about 5%. But when higher volumes of fibres are added like 0.55% to 0.60%, then the compressive strength decreases from original by 3- 5%. The results in Table 2 seem to indicate that there may be an effective volume threshold.
 - The split tensile strength of concrete is about 10 % of its compressive strength. Addition of fibers to a concrete mix improves the tensile properties of concrete. The fibers act as crack arresters in the concrete matrix controlling and terminate the propagation of crack.
 - Flexural strength: Flexure strength behaviour in reinforced beam and plain concrete have similarities with change of maximum load bearing ration from 0.20% to 0.35 % which is understandably due to activity of fibres in arresting tensile loads .
 - Shrinkage cracking: There are two major cracking in concrete - Cracking due to hardening and Plastic shrinkage cracking. Polypropylene helps in reduction of plastic shrinkage cracking. by using about 0.35% fibers by volume reduce plastic shrinkage cracking to such an extent that no cracks can be seen. and lower volumes i.e. 0.15 to 0.20% visibly restrained the crack width compared to samples that were not fiber reinforced. The shrinkage cracking is reduced by 83 to 85% by addition of fibers upto 0.35% and 0.50 %. Permeability of concrete greatly decreases by polypropylene fibers therefore controlling the cracks which

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(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

indirectly increase concrete life and service, as its resistance against the chemicals is also increased. Actually fibers can act as crack bridging mechanism and can improve cracking resistance. The controlled cracking can be seen as a useful economical advantage as: -

1. Better split tensile strength is achieved with the addition of the steel powder waste in concrete. The strength has increased upto 40.87% when compared to that of the control concrete specimen.
2. In flexure the specimen with steel scrap as waste material was found to be good. While adding it, the flexural strength increased by 25.88% that of the conventional concrete.

V.SCOPE AND CONCLUSION

This paper primarily reviews the various effects of addition of fibres in concrete with regard to compression, durability, flexure, impact energy, permeability, fresh concrete properties and toughness. Apart from checking the strength variation comparison between the percentages of fibre with respect to the concrete volume is presented. And hence the optimum amount of percentage of fibres with respect to maximizing strength, durability and utility are to be noted. Thus multi modal waste fibres with volume not affecting workability can produce FRC with great mechanical properties. In future, FRC design fundamentals for waste, macro and crimped fibres can be established for both metal and plastic fibres. This has a great future and can give us economical, sustainable and durable concrete.

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