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An Effective Waste Management Solution by Incorporating Fibres Made from waste PET bottles in Concrete- A Review

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Abstract : Plastics are astounding discovery of man and has become an indispensable and inseparable part of a common man's life. The disposing off of several existing forms of plastics in nature has always been a key matter of concern to man. Polyethylene terephthalate, commonly known as PET is commonly and widely used for developing plastic bottles which in turn are consumed for packaging of different kinds of beverage products packaging. In spite of its various uses, there are issues of its biodegradability which poses a strain to environment. Plastics are one of such products which are littering the oceans and environment. Hence there is a dreadful requirement of some solution to effectively solve this problem of disposal to reduce the environmental strain. The researchers are trying to incorporate one waste product or the other into concrete so that it can help in a dual way- decreasing the strain on environment and the effective utilization by enhancement of various mechanical properties of concrete. Research studies have made it quite clear that the PET waste has the capability to enhance various parameters of concrete which is a far better option than sending it to landfill. The research studies on PET fibers have also confirmed one more thing that these can be more effectively utilized by modifying the shape of fibers and their bonding properties. The present study is focused on reviewing the use of various aspect ratios(length to breadth ratio) and shapes of plastic fibers in concrete

Introduction: -

Concrete is a simulated, extensively and comprehensively used material in construction industry[35-47]. It is ranked second in terms of consumption of various available materials on earth after water[24].The reason for such a wide utilization lies in the fact that it has high compressive strength. The usage is also contributed to the easy availability of the ingredients and prolonged existence[33]. It is imperative that a structure, in addition to exhibiting strength should also be durable while resisting weathering action, chemical attacks etc. Concrete also has its disadvantage in terms of low tensile strength and cracking.[41] Research studies have been extended to the study of reinforcing various fibers to overcome this disadvantage of concrete in order to make it advantageous in terms of cracking and tensile strength[26-47].The use of various short fibers including PET fibers as reinforcement in suitable shapes can help up to some extent to overcome this limitation[1]. This type of concrete is known as fiber reinforced concrete. It can be defined as a amalgamated material constituted of Portland cement, aggregate, and incorporating short isolated and irregular fibers[27].There is wide range of applications of PET due to the flexibility inculcated in them. However, the major purpose of PET includes food, alcoholic as well as hot beverages, carbonated and non carbonated drinks etc. The collective portion of carbonated and bottled water was seen to constitute a 65.05% portion of the on the whole PET market in year 2010. Since PET is broadly utilized in the production of CSD bottles, its requirement in the area of bottled water stood second of all[2]. This paper is primarily based on the results obtained by various researchers after incorporation of PET fibers made from plastic bottles to concrete. Research studies done on PET fibers have revealed that the incorporation of PET fibers has influence on various aspects like workability and strength parameters of the matrix. The abrasion characteristics of the resulting matrix have also seen to be enhanced with PET fibers inclusion. The PET bottles would appear to be low-cost materials which would help to resolve solid waste problems and preventing environment pollution[3].Additionally, researchers have recommended that there must

be some suitable way to increase the bonding properties of PET fibers by using some coating phenomenon by treating the surface of the plastic with some reactive material[4].

Management of solid waste including plastic waste is in dejected states in India. The solid waste usually embrace of fiber produced from from spinning unit, waste fabric from textile units , packaging supplies as well as sludge produced from effluent handling units [24]. The scarcity of appropriate collection systems leads to littering of wastes at public places resulting in unhygienic conditions. Lack of segregation of waste at source or at collection points is creating problems for management of waste[29]. Industries producing plastics along with other solid wastes still lack a viable solution for their waste disposal. The gradually accumulating waste is causing havoc when it takes the route of air and ground [30]

The packaging material like PET are part of common man's life and are causing heavy pollution. Some facts on PET bottles and plastic waste usage and recycling are presented below:-

1. According to 'National Association of PET Container Resources', only a fraction of PET bottles are recycled and a substantial amount is sent into landfill as wastage thereby creating a potential pollution source. Energy use and greenhouse gas emission can be successively reduced by 84% and 71% respectively if one pound of PET flake is recycled[5].

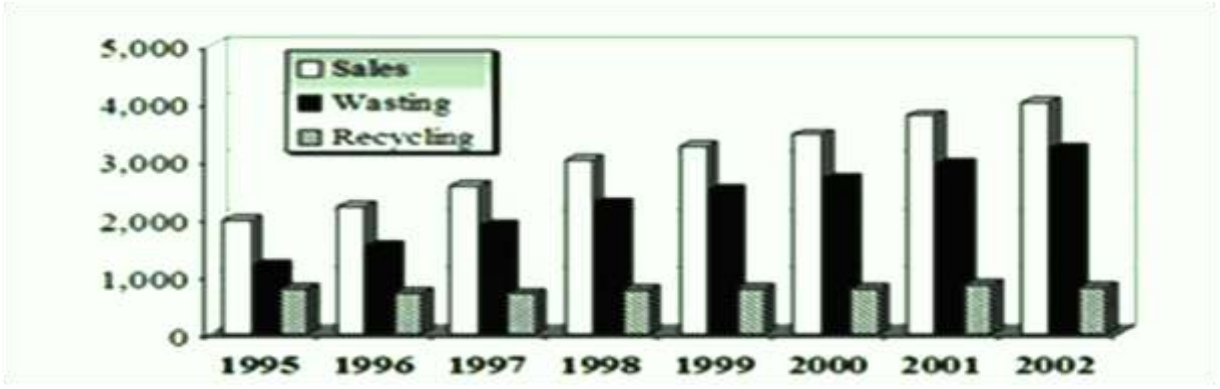

Figure 1:- PET bottles sales, recycling and wasting 1995- 2002 (millions of pounds) Source:- National Association of PET Container Resources

2. China has been ranked first among major plastic contributors to oceans by sharing 28% of the world's annual marine plastic pollution in 2015[6]

3. The plastic consumption in India has seen a hike from 61000 tons in the year 1996 to 8,500,000 tons till 2007. Globally there has been an increase of 620% plastic waste production since 1975[7]. Including plastics, huge tones of waste material were generated from industries per annum and it is estimated as 300 million tones[31]

4. The reports of Central Pollution Control Board of India have shown an increase from 61,000 tones in 1996 to 8,500,00 tones in plastic consumption. The reports of National Plastic Waste Management task force have also clearly depicted an alarming increase in demand of PET bottles as there has been an increased demand of 0.26 Million tons of PET from 1995-96 to 2006-07, which is a great environmental issue as there must be disposal technique available for such a treacherous, non biodegradable pollutant as the majority of PET bottles directly sent to landfill[8].

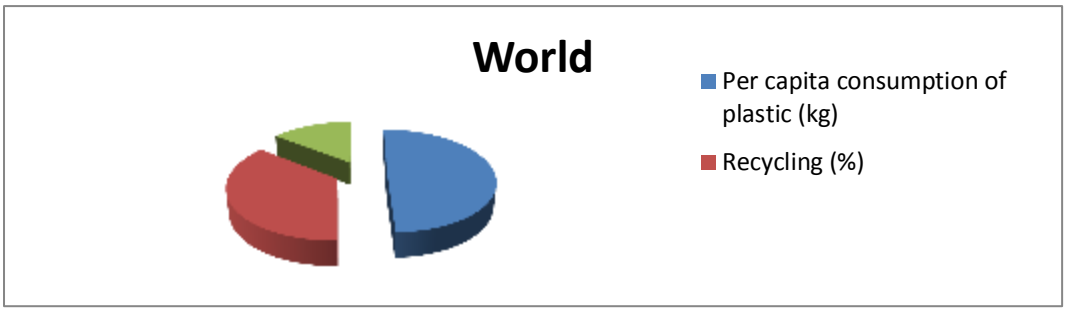

Figure 2:- Consumption and recycling of Plastic worldwide [8]

5. Dasgupta and Khurana, 2008 found that an average 25,03,334 virgin plastic bottles were employed for the purpose of packing carbonated soft drink along with water bottles per month in Mumbai city of India. Also a huge amount of the plastic containers thrown away after single usage, becoming a major ground of contamination of river bodies. approximately 67% of waste bottles have been sent to landfill in Asia. Out of this, only 8% are recycled[9]. However, India's rate of recycling of plastic waste is relatively highest in comparison to major plastic producers of the world[9]

6. The Los Angeles area of U.S. alone contributes 10 metric ton of plastic waste including PET bottles everyday into Pacific Ocean. Due to the presence of plastic in oceans, approximately one million sea birds and 100,000 marine mammals are killed every year[10].

In view of all the above facts and information, it becomes essential to solve this environmental problem. The utilization of various waste products like plastics in concrete will lead to green environment[32]. The incorporation of plastics in the form of PET fibers with different aspect ratios in concrete so that it can modify the properties of concrete and solve the disposal problem to some extent. Various research studies have shown improvements in concrete properties due to incorporation of PET fibers as discussed in table 1.

Materials and Methodology

A comparison in terms of strength parameters and fresh properties was made between conventional concrete specimens and concrete specimens made from incorporating PET fibers made from PET bottles either as a replacement or direct inclusion. These were collected either from landfill or other open sources. The fibers were extruded manually by cutting them in the form of long narrow strips by maintain the constant width and desired length to get suitable aspect ratio.

Different methods for determining the strength parameters as well as influence on various fresh properties were employed by researchers. For strength determination, various researchers used compressive strength test, split tensile strength and flexural tensile strength. For evaluating fresh properties, workability standard methods-slump test and compaction factor test was used. The incorporation of PET fibers was found to improve strength parameters of concrete.

Results and Discussions:-

The results obtained by different researchers on using different aspect ratios in concrete have been tabulated below:-

Table 1:- Effect of adding PET fiber in concrete

S.NO	Authors / References	Methodology employed	Main findings
1)	Kaothara et.al (2015)[11]	Replacing PET fibers with fine aggregates and Comparing workability and compressive strength aspects of concrete mix incorporated with PET fibre with controlled specimens at different volume fractions ranging from 0.5% to 3.0 % at an interval of 0.5% . Aim was to find out the effect on workability and strength parameters on incorporating PET fibers	Workability linearly decreased with fiber incorporation levels. For 3% volume fraction, there was a substantial decrease from 5 mm to 0 mm (Slump was 0 mm at 2 and 2.5% fiber content also). Compaction factor also decreased from 0.86 to 0.62 at 3% incorporation level. Strength improvements were seen only up to 1% fiber addition and there after decreased by substantial amounts.
2)	Asha and Resmi (2015)[12]	Aspect ratios- 8, 15and 23 Shape of fiber- Straight and Crimped Fibers used as direct inclusion by volume of concrete ranging from 0.5 % to 1.5 % Aim was to compare the mechanical properties and workability of straight and crimped fibers with controlled specimens	Workability decreased by fiber addition at all addition levels as well as aspect ratios. Slump values were relatively higher for straight fibers than crimped ones. Strength becomes optimum at 1% volume fraction. Strength was higher for aspect ratio 15 than others. Crimped fibers provide greater strength than straight ones
3)	Nibudey et.al (2014)[13]	Aspect ratio- 35 and 50 Shape of fiber- straight only Fibers used by volume of concrete matrix at 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0% volume fraction Aim was to check compressive strength and sorptivity of M20 and M30 concrete specimens incorporated with PET fibers	For both the grades, sorptivity (depth of water absorption) decreased upto 1% fiber content and then decreased for higher volume levels. Strength increased only upto 1% fiber content for both the grades. M20 grade with aspect ratio 50 of fiber gave maximum increase in strength comparatively
4)	Prabhu et.al (2014)[3]	Aspect ratios- 17, 33 and 50 Shape of fibers- Straight only Fibers used as replacement of fine aggregates at different volume fractions from 0.5% to 1.5% Aim was to study the impact of aspect ratios and volume of fibers on concrete mix	Strength parameters improved with addition of fibers. Optimum level of strength was found at 1% volume fraction for all the aspect ratios as well as replacement levels. Strength was higher for aspect ratio 33 than other aspect ratios
5)	Raju et.al (2014)[4]	Aspect ratios- 15,30,45 and 60 Fibers were used by weight as replacement of fine aggregates at replacement levels of 0.1% and 0.5% Aim was to find the effect of different aspect ratios and weight	Slump values increased for aspect ratio 15, 30 and 45 and decreased for aspect ratio 60. Compressive strength improved significantly only at 0.1% replacement level at aspect ratio 15, 50 and 45.

		fractions of PET fiber on workability and mechanical properties of concrete mix	Similar trend was observed for split tensile as well as flexural strength.
6)	Hasan Taherkhani(2014)[14]	PET fibers of constant width 2 mm and length 1 cm, 2 cm and 3 cm were incorporated directly at 0.5% and 1% volume fraction of the matrix Aim was to check various strength aspects, abrasion characteristics and elastic modulus of the specimens incorporated with fibers	0.5% fiber content mix of all lengths was more workable. Compressive strength reduced with increasing fiber content as well as increasing lengths. It was least for 3 mm length and 1% fiber volume fraction. Bulk density of the fiber incorporated mixtures reduced from 2375 kg/m^3 to 2350 kg/m^3 and 2325 kg/m^3 at 1% fiber content and 1.5% respectively. Flexural strength was more for long fibers than smaller ones. It decreased with increasing fiber content. Split tensile strength decreased for all fiber contents. Resistance of PET fiber reinforced concrete to abrasion was good.
7)	Nibudey et.al (2013)[15]	Aspect ratios of fiber- 35 and 50 Fibers were added by volume of concrete at different levels ranging from 0% to 3% at an interval of 0.5% . Two grades M20 and M30 were used. Aim was to check compressive strength at different aspect ratios and volume fractions for both the grades	Compressive strength was highest at 7.35 % for M20 grade of concrete at aspect ratio 50 at 1 % fiber volume fraction. For M30 grade, the rate of increase was lesser comparatively to M20 grade. Maximum decrease was observed at 3 % fiber volume fraction and at aspect ratio 50. There was 27.07 % decline for M20 grade of concrete.
8)	Reddy and Kumar (2014)[16]	Aspect ratio of fiber- 69 Width – 5 to 7 mm Diameter of the ring -10cm Thickness-0.6mm. O- shaped fibers were used. Fibers were used by weight of cement at 0, 0.25%, 0.50 % and 0.75% 0.8 % super-plasticizer was used by weight of cement Aim was to find the impact of adding O shaped fibers in concrete mix	Increasing fiber content decreases the compressive strength. There were negligible improvements at all replacement levels. Split tensile strength and flexural strength increased for all levels. At 0.75% replacement level, 16.2 % and 33 % improvement in flexural tensile strength and split tensile strength respectively was observed over normal specimens.
9)	Mello et.al (2014)[17]	PET fibers of average length 50 mm and width 1.5 mm were used by volume of concrete at volume fractions of 0.5%, 1.0%, 1.5% and 2.3%	Workability was hampered for entire fiber volume fractions. Compaction and finishing problems were found beyond 1.0% fiber volume. Decrease

		Aim was to compare the workability and mechanical properties of normal and PET fiber reinforced concrete specimens	of 29%, 27.9%, 30.9% and 34.3% in compressive strength; 13.8%, 16.5%,19.7% and 25.7% in flexural strength; 30.4%, 25.7%, 27.6%, 22.3% was seen at 0.5%, 1.0%, 1.5% and 2.3% fiber incorporation level.
10]	Nibudey et.al (2014)[18]	Aspect ratios- 35 and 50 Concrete grades- M20 and M30. Fibers were added by volume of concrete at different levels ranging from 0% to 3% at an interval of 0.5% Aim was to study the effect of PET fiber with different aspect ratios on shear strength of concrete matrix	Maximum augmentation for shear strength was observed as 27.25 % at 1% PET volume level. Aspect ratio was 50 in M20 grade of concrete at the maximum strength
11]	Afroz et.al (2013)[19]	Aspect ratio 38 with length 40mm, width 1.5 mm and thickness 0.6 mm; added as volume fractions of mix as 0.40, 0.46 and 0.52% Aim was to study the impact of PET fiber incorporation on workability, split tensile strength and shear capacity of concrete mix	Workability decreased due to incorporation of fibers at all levels. Split tensile strength and shear capacity of specimens increased by 9, 16 and 25%; and 30, 70 and 50% at respective fiber volume fractions of 0.40, 0.46 and 0.52%
12]	Nibudey et.al (2013)[20]	Aspect ratio – 35 and 50 Concrete grade M30. Fibers were added by volume of concrete at different levels ranging from 0% to 3% at an interval of 0.5%. Aim was to compare the fresh and mechanical parameters of concrete mix with and without fiber incorporation	The workability and dry density of concrete mix decreased due to inclusion of fibers. For aspect ratio 50, strength enhancement was comparatively more. At 1% volume of fiber content, there was optimum increase of strength.
13]	Nibudey et.al (2013)[21]	Aspect ratio 35 and 50 Concrete grade M20 and M30 Fibers added as 0.5%, 1.0%, 1.5%, 2%, 2.5% and 3 % by volume of concrete mix. Aim of the study was to find relationship between cube and cylinder compressive strength of the controlled and fiber incorporated specimens	Linear relationship existed between cube and cylinder compressive strength. For M20 grade, the ratio was 1.253 for controlled specimens, 1.26 and 1.27 for aspect ratio 35 and 50 incorporated specimens respectively. For M30 grade, the ratio was 1.240 for controlled specimens, 1.27 and 1.24 for aspect ratio 35 and 50 incorporated specimens respectively.
14]	Shamskia (2012)[22]	Length of fiber- 40, 50 and 60 mm Width of fiber- 3 mm Fibers added directly as 0.5%, 1%,	Workability hampered due to fiber addition at all incorporation levels. Author

		1.5% and 2% by weight of cement mix Aim was to check workability and mechanical properties of concrete mix and compare them with normal concrete specimens	also described 50 mm and 60 mm long fiber incorporated mix as unstable. Slight decrease in compressive strength was seen at all levels of incorporation.
15	Fraternali et.al (2011)[23]	Straight PET fibers with length 40 mm and 52mm and diameter 1.10 and 0.70 mm respectively Crimped PET fibers with length 52mm and 0.70 mm. Fibers added as 1% by volume of concrete mix. Aim was to compare the mechanical properties and ductility characteristics of PET fiber reinforced concrete specimens and normal concrete specimens	40 mm long straight fibers led to 35%, 41%, 15% and 656% respective improvements; 52 mm long straight fibers led to 22%, 2%, 8% and 400% respective improvements; 8 to 12 %, 34% and 544% respective improvements in compressive strength, first crack strength, first crack ductility and ultimate ductility index.

Moreover the incorporation of fibers have seen to impart more ductility to concrete specimens as these fiber incorporated specimens took more time to break down into pieces than normal concrete specimens[15].

Figure 3:- Ductile behaviour of compressive strenght specimen(left) and tensile strength specimen (right) with and without PET fibers(Nibudey et.al 2013)[15]

Conclusions:-

From the research studies on PET fibers, it can be concluded that:-

1. Incorporation of PET fibers leads to decrease in workability. This may be due to the fact that the larger surface area provided by higher aspect ratio of PET fibers can lead to loss of slump.
2. There are considerable improvements in strength parameters on inclusion of PET fibers only up to certain volume fraction. Straight PET fibers cannot provide more strength and hence their shape needs to be modified. Crimped fibers can cause more enhancements in strength. Also O-shaped fibers can augment split tensile and flexural tensile strength considerably.
3. Shear strength of concrete specimens made with PET fibers augments in an effective manner as compared to the normal concrete specimens.
4. Aspect ratio and dosage of PET both affect the flow and strength parameters of concrete. Higher aspect ratios affect the workability and strength significantly.
5. The depth of water absorption or sorptivity values increase due to more volume incorporation of fibers.
6. The use of PET fibers can make concrete more abrasion resistant and light weight as compared to normal concrete specimens.
7. The ductility characteristics of concrete specimens made with PET fibers enhances in comparison to conventional concrete specimens. The normal specimens which were broken down suddenly on application

of load took time to break into pieces when incorporated with PET fibers. The incorporation of fibers can improve first crack strength and ultimate ductility index.

8. In order to utilize large volume fractions of concrete, there needs to be some coating sort of phenomenon to fibers with some mineral admixtures so that more strength improvements can be made.
9. Limited literature is available for PET fibers with aspect ratios in concrete and more aspect ratios need to be studied.

Scope for future research:-

1. Long term study of PET fiber reinforced concrete can be done and some sort of coating mechanism to increase the bonding characteristics of PET fiber to concrete matrix need to be discovered.
2. Machine may be designed and developed for extruding bulk volumes of fibers in a short time

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