

**LABORATORY INVESTIGATIONS OF THE
PROPERTIES OF CONCRETE CONTAINING
RECYCLED PLASTIC AGGREGATES**

**A thesis report submitted
in partial fulfillment of the requirements for
the award of degree of**

**MASTER OF ENGINEERING
In
STRUCTURAL ENGINEERING**

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CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled, **“Laboratory investigations of the properties of concrete containing recycled plastic aggregates”**, being, in partial fulfillment of the requirements for the award of degree of *Master of Engineering* in *Structural Engineering* submitted in **Civil Engineering Department of Thapar University, Patiala**, is an authentic record of my own work carried out under the supervision of *Dr. Maneek Kumar* and *Mrs. Shweta Goyal* and refers other researcher’s works which are duly listed in the reference section.

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

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ABSTRACT

Solid waste management is one of the major environmental concerns in our country now a days. The present study covers the use or recycled plastics as replacement of coarse aggregates in concrete. The main aim of the study is to investigate the change in mechanical properties of concrete with the addition of plastics in concrete. Along with the mechanical properties, thermal characteristics of the resultant concrete is also studied

It is found that the use of plastic aggregates results in the formation of lightweight concrete. The compressive, as well as tensile strength of concrete reduces with the introduction of plastics. The most important change brought about by the use of plastics is that the thermal conductivity of concrete is reduced by using plastics in concrete. Therefore, it can be said that recycled plastics can be used for thermal insulation of buildings.

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CHAPTER 1

INTRODUCTION

1.1. GENERAL

Research concerning the use of by-products to augment the properties of concrete has been going on for many years. In the recent decades, the efforts have been made to use industry by-products such as fly ash, silica fume, ground granulated blast furnace slag (GGBS), glass cullet, etc., in civil constructions. The potential applications of industry by-products in concrete are as partial aggregate replacement or as partial cement replacement, depending on their chemical composition and grain size. The use of these materials in concrete comes from the environmental constraints in the safe disposal of these products.

Big attention is being focused on the environment and safeguarding of natural resources and recycling of wastes materials. Actually many industries are producing a significant number of products which incorporate scrap (residues). In the last 20 years, a lot of works concerning the use of several kinds of urban wastes in building materials industrials process have been published. Many researches have been extended to study new kinds of wastes to investigate deeply particular aspects. The addition of wastes, apart from the environmental benefits, also produces good effects on the properties of final products.

One of the new waste materials used in the concrete industry is recycled plastic. For solving the disposal of large amount of recycled plastic material, reuse of plastic in concrete industry is considered as the most feasible application. Recycled plastic can be used as coarse aggregate in concrete. However, it is important to underline that re-using of wastes is not yet economically advantageous, due to the high costs of transport and its effect on the total costs of production. Moreover, it is important not to neglect other costs, directly referable to the kind of wastes, due, in particular, to the need of measuring gas emission, during firing, and the presence of toxic and polluting elements.

1.2. PLASTICS

The word “plastic” means substances which have plasticity, and accordingly, anything that is formed in a soft state and used in a solid state can be called a plastic. Therefore, the origin of plastic forming can be traced back to the processing methods of natural high polymers such as lacquer, shellac, amber, horns, tusks, tortoiseshell, as well as inorganic substances such as clay, glass, and metals. Because the natural high polymer materials are not uniform in quality and lack mass productivity in many cases, from early times it has been demanded in particular to process them easily and into better quality and to substitute artificial materials for natural high polymers. Celluloid, synthetic rubber, ebonite, and rayon are these artificial materials. Presently, it is defined that the plastics are synthesized high polymers which have plasticity, and consequently substances made of these natural materials are precluded.

Plastics can be separated into two types. The first type is thermoplastic, which can be melted for recycling in the plastic industry. These plastics are polyethylene, polypropylene, polyamide, polyoxymethylene, polytetrafluorethylene, and polyethyleneterephthalate. The second type is thermosetting plastic. This plastic cannot be melted by heating because the molecular chains are bonded firmly with meshed crosslink. These plastic types are known as phenolic, melamine, unsaturated polyester, epoxy resin, silicone, and polyurethane. At present, these plastic wastes are disposed by either burning or burying. However, these processes are costly. If the thermosetting plastic waste can be reused, the pollution that is caused by the burning process as well as the cost of these waste management processes can be reduced. To achieve this purpose, a study of these thermosetting plastics for application into construction materials has been conducted, particularly for the concrete wall in buildings. In Thailand, lightweight concrete is extensively used for the construction of interior and exterior walls of buildings for the case where the walls are not designed for lateral loads. This is due to the special characteristics of lightweight concrete (*Panyakapo, 2007*).

The growth of the world plastic industry has been enormous, from a little over 3 million tones in 1955 to 30 million tones presently (*Jain et al., 1977*). This figure touched 100 million tones mark in 2001 (<http://www.wasteonline.org.uk>).

1.3. PLASTIC WASTE DISPOSAL

1.3.1. Generation of plastic waste

The quantity of solid waste is expanding rapidly. It is estimated that the rate of expansion is doubled every 10 years. This is due to the rapid growth of the population as well as the industrial sector (*Phai boon and Mallika, 2007*). In a report, the National Council on Public Works Improvement identified the solid-waste crisis as an area of the infrastructure with great needs for improvement (*Rebeiz et al., 1993*). The solid-waste crisis is important from an environmental and economical point of view. As landfill areas are rapidly depleting, the cost of solid-waste disposal is rapidly increasing. The cost for solid-waste management was, on an average, \$2.7-3.6/t in 1979. The cost is now more than \$18/t and, in many localities; the cost exceeds \$90/t ("Our" 1989).

Among the solid-waste materials, plastics have received a lot of attention because they are generally not biodegradable. On a weight basis, there are about 10 billion kg of plastic wastes in the U.S. per year, which represents about 7% by weight of the total solid wastes (*Thayer, 1989*). However, plastic wastes are very visible, since they constitute about 30% by volume of the total solid wastes (Kline 1989). (*Karim et al., 1992*). The various types of plastics in municipal wastes are Polyethylene terephthalate (PET), High density polyethylene (HDPE), Low density polyethylene (LDPE), Polypropylene(PP), Polystyrene (PS) etc.

The major users of plastic are the packaging industries, consuming about 41%, 20% in building and construction, 15% in distribution and large industries, 9% in electrical and electronic, 7% in automotive, 2% in agriculture and 6% in other uses. (*Zoorob and Suparma, 2000*)

Among the various types of plastics, the largest component of the plastic waste is low density polyethylene/linear low density polyethylene (LDPE) at about 23%, followed by 17.3% of high density polyethylene, 18.5% of polypropylene, 12.3% of polystyrene (PS/extended PS), 10.7% polyvinyl chloride, 8.5% polyethylene terephthalate and 9.7% of other types. (*Zoorob and Suparma, 2000*)

One of the environmental issues with the plastics is that in most regions is the large number of plastic bottles, ploy thins and other plastic materials are deposited in domestic wastes and landfills. These plastic materials are not easily biodegradable even after a long period. Due to this, more landfill space is needed for disposal every year. However, the plastics have many good characteristics which include versatility, lightness, hardness, low linear dilation coefficient and good chemical resistance. These qualities render it well apt for concrete production or for other uses in building industry. Along with this, since it is not easily biodegradable, it is thought that plastics can be utilized as inert matter in cement matrix. In particular, plastic material particles can be incorporated as aggregates in concrete.

As has already been mentioned, on an average, 20% of plastics is used in construction industry in various building application. However, in India, this figure is less than 2% at present. (*Jain et al, 1977*)

1.4. PLASTIC RECYCLING

Recycling is the practice of recovering used materials from the waste stream and then incorporating those same materials into the manufacturing process. Recycling is one of the prominent issues in this environmentally conscious era. There are three main arguments for recycling: first, it preserves the precious natural resources; secondly, it minimizes the transportation and its associated costs; and thirdly, it avoids the environmental load caused by waster material, i.e. space requirement. The great strides have been made to increase recycling rates worldwide in recent years. The major

consideration to support recycling all over the world is the expansion of infrastructure for recycling.

The need to recycle plastics is clear. Over 22 million tons of plastics are discarded each year in the trash. While plastics account for only 9.2% (in 2000) of the trash Americans generate each year, plastic products do not decompose in landfills and are difficult to reduce in size.

There are a few technological and economic constraints that currently limit the full and efficient recycling of plastic wastes into useful products.

1.4.1. Recycling methods and construction applications

The recycling of plastic before we use it in concrete includes the some modification and processing techniques these includes the following methods as given below:-

A) Chemical modification. Plastic can be recycled by chemical modification or depolymerization. The two ways to achieve depolymerization are hydrolysis (Chemical Decomposition) and pyrolysis (thermal decomposition). For example, PET (polyethylene terephthalate) can be chemically modified to produce unsaturated polyester, thermosets polyester typically used in bathtubs, boat hulls, and automobile exterior panels. Another example is the thermal decomposition of acrylic wastes into methyl methacrylate (MMA), a monomer typically used in aircraft windows and neon signs. The technology of depolymerizing single condensation polymers such as urethanes, PET (polyethylene terephthalate), nylon, and polymethyl methacrylate is relatively easy. However, it is much more complicated to chemically modify mixed plastics to produce useful and economical chemical feedstock

B) Mechanical recycling.

Mechanical recycling of plastics refers to processes which involve melting, shredding or granulation of waste plastics. Plastics must be sorted prior to mechanical recycling.

Technology is being introduced to sort plastics automatically, using various techniques such as X-ray fluorescence, infrared and near infrared spectroscopy, electrostatics and flotation. Following sorting, the plastic is either melted down directly and moulded into a new shape, or melted down after being shredded into flakes and then processed into granules called regranulate. The chemical and physical properties of these recycled materials were compared with similar products manufactured from virgin resins. The properties of a blow-moulded bottle prepared from 100% post-consumer high-density polyethylene (HDPE). This recycled polymer exceeded the materials specifications for virgin plastics designs. Similarly, a sample of thermoplastic polyolefin (TPO, 100% polypropylene), obtained entirely from shredder residue (SR), displayed sufficient material strength for future separation and reprocessing. A range of feedstock recycling technologies is currently being explored. These include: pyrolysis, hydrogenation, gasification and thermal-cracking. Feedstock recycling has a greater flexibility over composition and is more tolerant to impurities than mechanical recycling, although it is capital-intensive and requires very large quantities of used plastic for reprocessing to be economically viable.

C) Thermal reprocessing. Thermal reprocessing consists of heating a thermoplastic at very high temperatures, thus making the plastic flow. The plastic is then converted into a new product as it cools. This method does not involve the modification of the chemical composition of the plastics. For example, PET, being thermoplastic polyester, can be heated and reprocessed into building panels, fence posts, or fibers for carpeting. This process cannot be repeated indefinitely since repeated thermal reprocessing may eventually adversely affect the plastic properties. Thermal reprocessing is quite straightforward if it is applied to relatively pure thermoplastics. However, thermal reprocessing could not be applied to thermosets (such as cross linked polyesters) because they cannot soften at high temperatures without degrading. Thermal reprocessing becomes much more involved if various thermoplastics are mixed together. One way of doing is to separate the various plastics. Separation of various plastics can be easy or complicated depending on the source of the waste. The other way to thermally reprocess mixed plastics is to use special equipment that takes into account the different thermal properties or makes few demands on the melting behavior of the plastic wastes (i.e.,

compression molding or melting in salt bath) and does not require meticulous removal of non-plastic wastes. Systems/ mechanisms have been developed to reprocess mixed or commingled plastic wastes where plastics with lower melting point act as a matrix that carries other plastics and contaminants into the mould. Chemical agents, called compatibilizers, could be used to improve the adherence between different polymer phases

D) Fillers. Plastic waste can also be used as fillers with virgin resins or other materials like concretes or as fill material in road construction. In such applications, chemical composition of the plastics is generally not very significant. This is an easy way to recycle thermosets or contaminated plastics in second grade applications. One such use is thermoplastic wastes that are melted and coextruded or co-injected into mouldings with virgin resins. These virgin resins with superior properties are forced into the perimeter of the mold while the recycled plastics, with inferior properties, are injected in the center of the mold. Plastic wastes may also be used with some effectiveness as a partial replacement of inorganic aggregates in concrete applications to decrease the dead weight of structures. Similarly, recycled rubber can be used in asphaltic concrete mixes.

1.4.2. Production process of plastic forming

There are two types of plastics. One is called thermosetting resin which does not soften again once it is formed and hardened, and the other is called thermoplastic resin which becomes soft or hard when its temperature rises or falls.

1.5. RECYCLED PLASTIC PRODUCTS

Recycled plastic is the end product of plastic recycling, and is produced in nearly every variety as new ("virgin") plastic.

1.5.1. Classification of recycled plastic in concrete

-Virgin polypropylene:-The virgin polypropylene fibers are 19 mm (3/4 in.) long fibrillated fibers. These are in slender fiber-form.

-Melted processed plastic: - The recycled plastic (melted processed) is produced by drawing molten automobile bumpers into long strands, which are cut to 28 mm (1.1 in.) length. It is in slender fiber-form.

-Automobile shredded residue: - Automobile shredded residue comprised mainly mixed plastics and some rubber, with a maximum particle dimension of 19 mm (3/4 in.). It is in flake form.

-Shredded plastic:- The recycled plastic (shredded) is produced by shredding plastics obtained from a mixed plastic stream; the process yielded plastic flakes with a maximum planar dimension of 25 mm (1 in.). It is in flake form.

acrylic, nylon, high density polyethylene (HDPE), and low density polyethylene (LDPE)

-Electronic waste products:-These products are televisions and monitors to cell phones and CPUs.

-Food Waste Food: - Scraps can be turned into valuable soil amendments through the simple techniques of composting or feeding a worm box.

-Tires: - The recycled tires can be used in civil engineering applications, or combusted as fuel.

-Beverage Containers

- Plastic Trash Bag

- Rigid Plastic Packaging Containers

- Recycled Plastic Lumber

- Recycled-Content Product

- Construction debris

1.5.2. Types of recycled plastic

The quantity of plastics consumed annually all over the world has been growing phenomenally. Its exceptionally user-friendly characteristics/features, unique flexibility,

Fabricatability and processability coupled with immense cost-effectiveness and longevity are the main reasons for such astronomical growth. Besides its wide use in packaging, automotive and industrial applications, plastics are also extensively used in medical delivery systems, artificial implants and other healthcare applications, water desalination and bacteria removal, preservation and distribution of food, housing appliances, communication and the electronics industry, etc. the uses of plastics and recycled plastics. The types of recycled plastics are shown in tabular form in [Table 1.1](#).

1.6. PROBLEMS IN RECYCLING OF PLASTICS

Plastics can be degraded very slowly. Photo degradation can breakdown plastic resin, but this process can take decades. Even longer, biodegradation of plastics takes centuries. The largest problem in recycling plastics is separating the plastics by type and number. In the current recycling system, the plastics must be separated by type. During the reprocessing of plastic containers, if the plastic is not of a uniform type, the raw plastic resin is unusable in the manufacturing industry.

Table 1.1 Types of recycled plastics

Plastic ID code	Name of Plastic	Description	Range of Products	Uses for Plastic made from Recycled Waste Plastic
1	Polyethylene terephthalate	Clear tough plastic	Soft drink & mineral water bottles	Soft drink bottles; detergent bottles; clear packaging film; fleecy jackets; carpet fibers.
2	High density polyethylene (HDPE)	Usually white or colored. Very common plastic	Milk, cream, shampoo and cleaner bottles; milk crates; freezer bags.	Compost bins; Mobile garbage bins; agricultural pipes.
3	Unplasticised polyvinyl chloride (UPVC) Plasticized polyvinyl chloride (PPVC)	Hard rigid plastic may be clear. Flexible clear elastic plastic.	Clear cordial & juice bottles: plumbing fittings Garden hoses, shoe soles.	Detergent bottles; hoses; tiles; plumbing pipes & fittings.
4	Low density polyethylene (LDPE)	Soft, flexible plastic.	Garbage bags, black plastic sheet; ice-cream container lids.	Film & bags for building and packaging.
5	Polypropylene (PP)	Hard but flexible plastic	Ice-cream containers, drinking straws, potato crisp bags.	Compost bins; Kerbside recycling crates.
6	Polystyrene (PS) Expanded polystyrene (UPS)	Rigid, brittle plastic. May be clear or glassy.	Yoghurt containers; plastic cutlery. Hot drink cups; meat trays; packaging.	Clothes pegs, coat hangers, video & CD boxes.

Once the problem of sorting the resins has been overcome, the recycling loop is still not closed. Reprocessed plastic resin faces a weak market. Simply collecting plastic for

recycling does not mean that there will be a manufacturer willing to pay for the raw material. Recycled plastic resin has limited value as a manufacturing resource because its quality degrades every time it is reheated during the recycling process. Consequently, most plastic is only reprocessed once before it goes to a landfill. "Down cycling" is a more accurate term than "recycling" when it comes to plastic. Unlike glass or paper, plastic recycling does not "close the loop" because most post consumer bottles are not made into new plastic bottles. Instead, milk jugs, soda containers and other bottles are turned into lower-grade products such as jacket fill, fleece, carpet, toys or plastic lumber. None of these products are in turn recyclable. Therefore the recycling process only delays the plastic's disposal. The final destination for all plastic is a landfill, where it does not decompose, or an incinerator, where it can release harmful chemicals into the atmosphere when burned.

1.7. ADVANTAGES AND DISADVANTAGES OF USING PLASTICS

1.7.1. Advantages of using plastics in concrete

The growth in the use of plastic is due to its beneficial properties, which include:

- Extreme versatility and ability to be tailored to meet specific technical needs.
- Lighter weight than competing materials reducing fuel consumption during transportation.
- Durability and longevity.
- Resistance to chemicals, water and impact.
- Excellent thermal and electrical insulation properties.
- Comparatively lesser production cost.

- Unique ability to combine with other materials like aluminum foil, paper, adhesives.
- Far superior aesthetic appeal.
- Material of choice – human life style and plastic are inseparable.
- Intelligent features, smart materials and smart systems.
- Reduction of municipal solid wastes being land filled and
- An alternative to pressure-treated lumber that leaches toxic chemicals into water.

1.7.2. Disadvantages of plastics

The followings are the main disadvantages of using the plastics in concrete are as follows:-

- Plastics are having low bonding properties so that the strength of concrete gets reduced such as compressive, tensile and flexural strength.
- Its melting point is low so that it cannot be used in furnaces because it gets melt as its comes in contact with the heat at high temperature.

Plastics production also involves the use of potentially harmful chemicals, which are added as stabilizers or colorants. Many of these have not undergone an environmental risk assessment and their impact on human health and the environment is currently uncertain. Such an example is phthalates, which are used in the manufacture of PVC. PVC has in the past been used in toys and there has been concern that phthalates may be released when these toys are sucked (come into contact with saliva).

Risk assessments of the effects of phthalates on the environment are currently being carried out. The disposal of plastics products also contributes significantly to their environmental impact. Because most plastics are non-degradable, they take a long time to

break down, possibly up to hundreds of years although no-one know for certain as plastics have not existed for long enough when they are landfilled. With more and more plastics products, particularly plastics packaging, being disposed of soon after their purchase, the landfill space required by plastics waste is a growing concern.

1.8. NEED FOR FURTHER WORK

It is necessary to work out a project proposal to carry out further studies on various aspects such as collection, processing and effective utilization of this waste material. To start with, such a study could be initiated with the following components:

- i) Estimation of the types, quantity and useful components present in the waste plastic materials in the city and surrounding areas.
- ii) Methodology for collection and sorting out the useful components of the plastic waste.
- iii) Methodology for processing the plastic bags as required for use in the preparation of modified bitumen, including cleaning, shredding and further processing of the plastic waste materials.
- iv) Identification of two or three construction companies / entrepreneurs who could incorporate appropriate mixing units in their hot mix plant to add and mix the required proportion of the processed plastic additive
- v) Carrying out further laboratory investigations, construction of some test tracks and field studies on the performance of concrete using the modified concrete.
- vi) Working out relative economics of using the modified concrete mixes in road construction works, considering the improved performance and increased service life of the pavement.
- vii) Preparation of specifications and standards for the construction industry.

It is hoped that on completion of the above project, the plastic waste materials will be put to effective use in construction industry, resulting in improved road pavements, concrete structures and also relief from the waste plastic materials being littered all around urban areas.

1.9. FORMATION OF THESIS

This thesis is presented in seven chapters as detailed below:

Chapter-1 Gives the introduction to recycled plastics and its resources and recycling methods for the waste plastic.

Chapter-2 Literature review presents the work done by various researchers in the field of concrete structure.

Chapter-3 Details the scheme of experimentation, materials used, variables involved, concrete mixes, mix design, casting and testing of specimens and materials.

Chapter-4 Gives results of various parameters studied and are compared with control concrete.

Chapter-5 Gives the major conclusions made in the study and the future scope of the study.

Chapter-6 References and appendices follow in succession.

CHAPTER 2

LITERATURE REVIEW

In this chapter the research work concerning to the various application and methods used for testing of the concrete made by recycled plastics aggregates are discussed. This chapter gives a comprehensive review of the work carried out by various researchers in the field of using recycled plastics in concrete as full or partial replacement of aggregates.

2.1. FRESH CONCRETE PROPERTIES

The most important property of concrete in fresh state is its workability. It is defined as the ease with which concrete can be mixed, transported, placed and finished easily without segregation. Workability has a broad range from very low (at slump = 0–25 mm) applied for vibrated concrete in roads or other large sections, to high workability (at slump = 100 –180 mm) applied for sections with congested reinforcement (*Koehler and Fowler, 2003*).

Batayneh et al. (2007) investigated the effect of ground plastic on the slump of concrete. Concrete mixes of up to 20% of plastic particles are proportioned to partially replace the fine aggregates. Details of mixture proportions and slump test results are given in [Table 2.1](#). It was observed that there is a decrease in the slump with the increase in the plastic particle content. As shown in [Fig. 2.1.](#), for a 20% replacement, the slump has decreased to 25% of the original slump value with 0% plastic particle content. This decrease in the slump value is due to the shape of plastic particles, i.e., the plastic particles have sharper edges than the fine aggregate. Since the slump value at 20% plastic particle content is 58 mm, this value can be considered acceptable and the mix can be considered workable. Along with plastics, glass and crushed concrete was also used as replacement of coarse aggregates and it was observed that use of crushed aggregates leads to maximum slump reduction, while using crushed glass has least effect on slump of resultant concrete.

Table 2.1 Mix proportions and fresh concrete properties (Batayneh et al., 2007)

Plastic (%)	Mix proportions(kg/m ³)					w/c ratio	Slump(mm)
	water	Cement	CA	FA	Plastic		
0	252	446	961	585	0	0.56	78
5	252	446	961	555.7	17.8	0.56	73
10	252	446	961	526.5	35.5	0.56	69
15	252	446	961	497.2	53.2	0.56	63
20	252	446	961	468.0	71.0	0.56	57

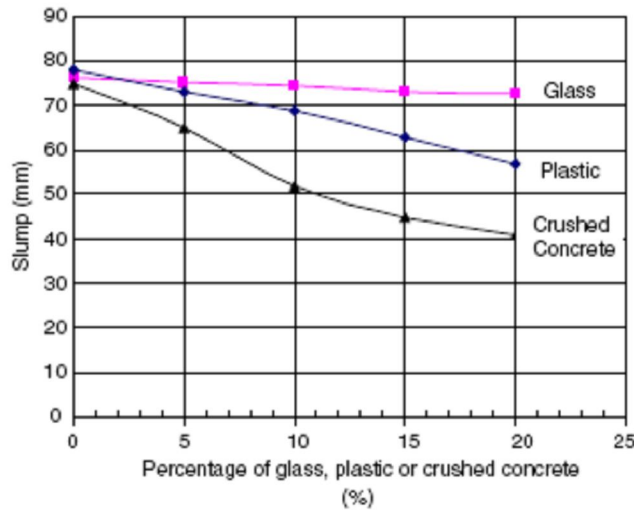


Fig.2.1. Workability verses percentage of different wastes in the concrete mixes.

(Batayneh et al., 2007)

Bayasi and Zeng (1993) studied the effects of polypropylene fibers on the slump and inverted slump cone time of concrete mixes. They reported the increase in inverted slump cone time with the increase in percentage of plastics. It was further reported that for fiber volume fractions less than or equal to 0.3%, fiber effect on fresh mix workability is insignificant and rather inconsistent; and for fiber volume of 0.5%, however, fibers appeared to adversely affect fresh mix workability, more evident by the increase in inverted slump cone time with 19 mm fibers with a more pronounced effect than 12.7 mm fibers.

Al-Manaseer and Dalal (1997) determined the slump of concrete mixes made with plastic aggregates. They reported that there was increase in slump when plastic aggregates were

incorporated in concrete. The concrete containing 50% plastic aggregates had a slightly higher cone slump than the concrete without plastic aggregates. Along with the slump test, K-slump test was also carried out. K-slump consistency results showed a similar pattern to that obtained from the cone slump. They concluded that the plastic aggregates neither absorbed nor added any water to the concrete mix. Due to this non-absorptive characteristic, concrete mixes containing plastic aggregates will have more free water. Consequently, the slump increased as shown in [Table 2.2](#).

Table 2.2 Cone and slump data (*Al-Manaseer and Dalal, 1997*)

Plastic aggregate (%)	Consistency(mm)			Workability(mm)			Cone slump(mm)		
	w/c	w/c	w/c	w/c	w/c	w/c	w/c	w/c	w/c
	0.28	0.40	0.50	0.28	0.40	0.50	0.28	0.40	0.50
0	65	70	70	50	55	55	178	190	-
10	60	73	65	55	60	45	-	190	-
30	75	70	75	60	45	50	178	-	-
50	73	83	80	55	60	50	206	216	-

Soroushian et al. (2003) reported reduction in slump with the use of recycled plastic in concrete. Slump test results are shown in [Fig.2.2](#). It is evident that the addition of any discrete reinforcement caused slump loss. While non-slender plastic particles, automobile shredded residue, and flakes were used at dosages that were in order of magnitude of those of slender fibers, their effects on fresh mixture properties were comparable. This could be attributed to the pronounced adverse effects of highly slender fibers on fresh mixture workability.

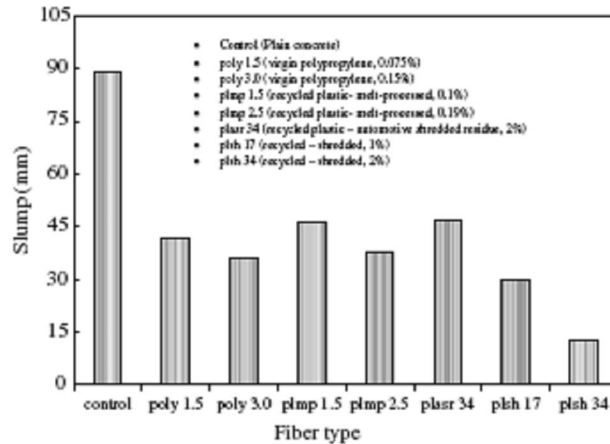


Fig.2.2. Slump test versus plastic fiber type (*Soroushian et al., 2003*).

Choi et al. (2005) investigated the influence of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) on the workability (slump) of concrete. Mixture proportions of concrete were planned so that the water–cement ratios were 45%, 49%, and 53%, and the replacement ratios of WPLA were 0%, 25%, 50%, and 75% by volume of fine aggregate. They reported that slump value of waste PET bottles lightweight aggregate concrete (WPLAC) increased with the increase in water–cement ratio and the replacement ratio. The improvement ratios of workability represent 52%, 104%, and 123% in comparison with that of normal concrete at the water–cement ratios of 45%, 49%, and 53%, respectively. This may be attributed to not only the spherical and smooth shape but also to the absorption of WPLA.

Saradhi et al. (2004) shown that the fresh concrete with expanded plastics mixes showed better flow values compared to the normal concrete at similar water cement ratio and also no segregation was observed in any mix even though the concretes were made without the addition of bonding additives. Also, it was noted that the EPS (expanded plastics) aggregates are compressed during the mixing operation and the resulting densities of concrete are generally higher than the designed densities by about 50–100 kg/m³. This effect was noted more in mixtures containing normal coarse aggregate.

Elzafraney et al. (2005) noticed that high recycled content concrete produced under field conditions successfully satisfied the targeted performance requirements of the project. Slump ASTM C-143 and air content ASTM C-231 for both mixtures were measured. The slump was 60 and 45 mm for normal and high-recycled-content concretes, respectively. The air content was 6 and 10.5% for normal and high- recycled content concretes, respectively.

Babu et al. (2004) studied that all the expanded plastic mixes showed better flow and no segregation was observed in any mix even in these concretes made without the addition of bonding additives. *Raghvan et al (1998)* have reported that mortars incorporating rubber shreds achieved workability comparable to or better than a control mortar without rubber particles.

Khatib and Bayomy (1999) investigated the workability of rubcrete and reported that there is a decrease in slump with increase in rubber content as a percentage of total aggregate volume. They further noted that at rubber contents of 40%, slump was almost zero and concrete was not workable manually. It was also observed that mixtures made with fine crumb rubber were more workable than those with coarse tire chips or a combination of tire chips and crumb rubber.

Ismail and Hashmi (2007) has found that the slump is prone to decreasing sharply with increasing the waste plastic ratio as shown in [Fig.2.3](#). This reduction can be attributed to the fact that some particles are angular and others have non-uniform shapes resulting in less fluidity. In spite of the slump reduction, the waste plastic concrete mixtures have easy workability and are suitable for use in precast applications and large sites based on the following consideration:

Siddique and Naik (2004) have reported that mortars incorporating rubber shreds achieved workability comparable to or better than a control mortar without rubber particles. It was also observed that mixtures made with fine crumb rubber were more workable than those with coarse tire chips or a combination of tire chips and crumb rubber.

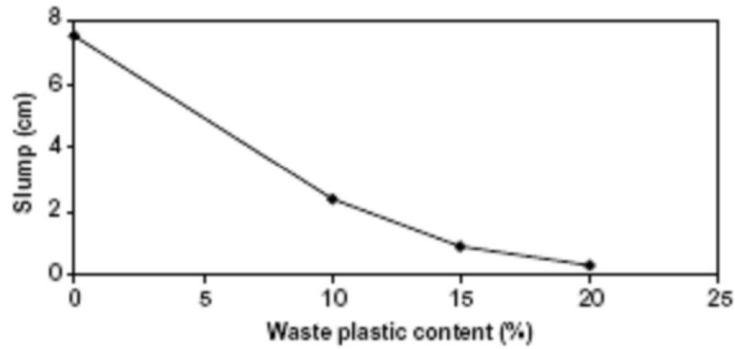


Fig.2.3. Slump of waste plastic concrete (*Ismail and Hashmi (2007)*)

2.2. DENSITY OF CONCRETE

The density of concrete is studied in terms of bulk density, fresh density and dry density and the same is discussed here under

2.2.1. Bulk density

Al-Manaseer and Dalal (1997) investigated the effect of plastic aggregates on the bulk density of concrete. They concluded that the bulk density of concrete decreased with the increase in plastic aggregates content (*Fig. 2.4*). The reduction in bulk density was found to be directly proportional to the plastic aggregates content, density of concrete reduced by 2.5%, 6%, and 13% for concrete containing 10%, 30%, and 50% plastic aggregates, respectively. Reduction in density was attributed to the lower unit weight of the plastics

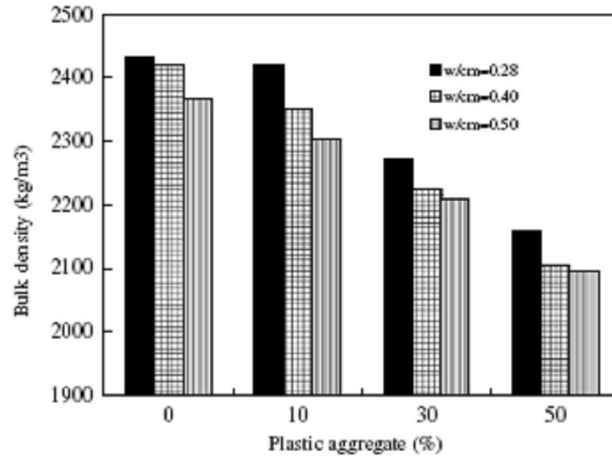


Fig.2.4. Bulk density versus plastic aggregates percentage (*Al-Manaseer and Dalal, 1997*)

2.2.2. Fresh density

Ismail and Al-Hashmi (2007) has found that the fresh density tends to decrease by 5%, 7%, and 8.7% as compared to the reference mix, when the percentage of plastics, used as replacement of sand is increased from 10% to 20% (as shown in Fig.2.5). This trend may be attributed to the density of the waste plastic being lower than the sand by 69.7%, which leads to a reduction in the fresh density. However, these fresh densities are averaged to the density of the plain concrete mixtures fresh.

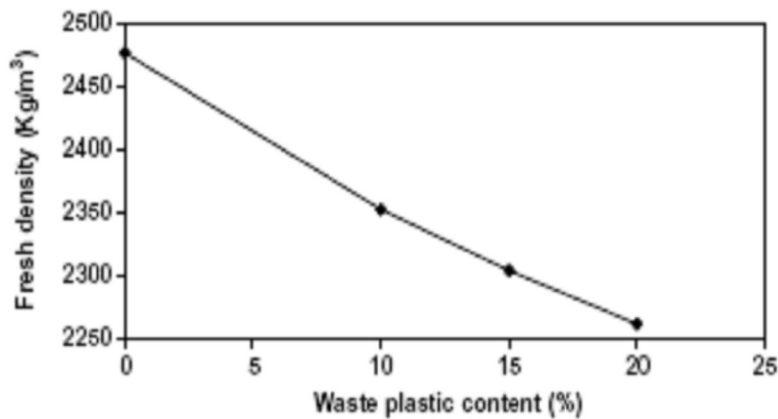


Fig.2.5. Fresh concrete density (*Ismail and Al-Hashmi, 2007*)

2.2.3. Dry density

Ismail and Hashmi (2007) studied that the dry densities at each curing age tend to increase with increasing the waste plastic ratio in each concrete mixture, but the dry densities tend to increase with time for each concrete mixture at all curing ages as shown in Fig.2.6. It is clear that at 28 days curing age, the lowest dry density (2223.7 kg/m³) exceeds the range of the dry density for structural lightweight concrete. The use of waste plastic for each curing age reduced the dry densities of all mixtures with increasing the waste plastic ratio, because the density of plastic is lower than that of sand by 69.7%.

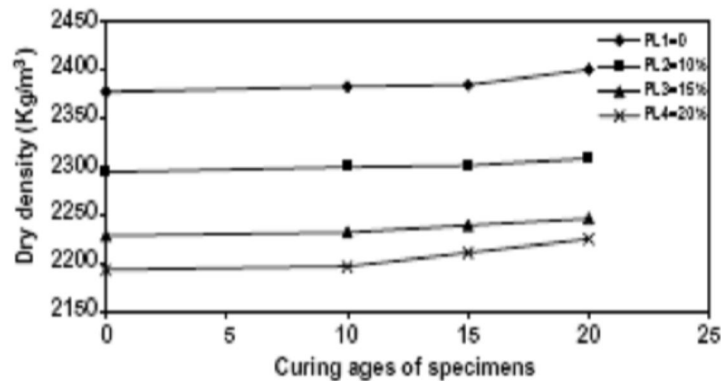


Fig.2.6. Dry density of plastic added concrete (*Ismail and Hashmi, 2007*)

2.3. AIR CONTENT

Siddique and Naik (2004), *Fedroff et al. (1996)* have reported higher air content in rubbercrete mixtures than control mixtures even without the use of air-entraining admixture (AEA). Similar observations were also made by (*Khatib and Bayomy, 1999*). This may be due to the non-polar nature of rubber particles and their tendency to entrap air in their rough surfaces. Also when rubber is added to a concrete mixture, it may attract air as it has the tendency to repel water, and then air may adhere to the rubber particles. Therefore, increasing the rubber content results in higher air contents in rubbercrete mixtures, thereby decreasing the unit weight of the mixtures

Bayasi and Zeng (1993) studied the effect of polypropylene fibers on the air content of concrete. They reported that air content increased with the inclusion of polypropylene fibers, and there was no detectable effect on air content of fresh concrete at volume below 0.3%.

Soroushian et al. (2003) reported that inclusion of recycled plastic in concrete resulted in the reduction of air content. The dosages of various virgin and recycled discrete reinforcement systems considered in the investigation are given in [Table 2.3](#). The air content of concrete made by using different types of recycled plastics is shown in [Fig. 2.7](#). It can be seen from the figure that the use of recycled plastic fibres causes a significant loss (approximately 1%) in air content. (*Mehta and Monteiro, 1993*) also reported that slump loss reduced the efficiency of air entrainment in the fresh concrete.

Table 2.3 Fresh concrete properties of polypropylene reinforced concrete (*Bayasi and Zeng, 1993*)

Mix no.	Fiber length(mm)	Fiber volume fraction (%)	Air content (%)
1	-	0	2.0
2	12.7	0.1	1.5
3	12.7	0.3	2.5
4	12.7	0.5	4.5
5	19.0	0.1	1.5
6	19.0	0.3	3.5
7	19.0	0.5	5.0

Mix 1 is the control mix in which there are no fibers (consists of cement content 424 kg/m³, water–cement ratio = 0.41, aggregate–cement = 4.0, dry aggregate content = 1696 kg/m³, superplasticizers–cement ratio =0.01)

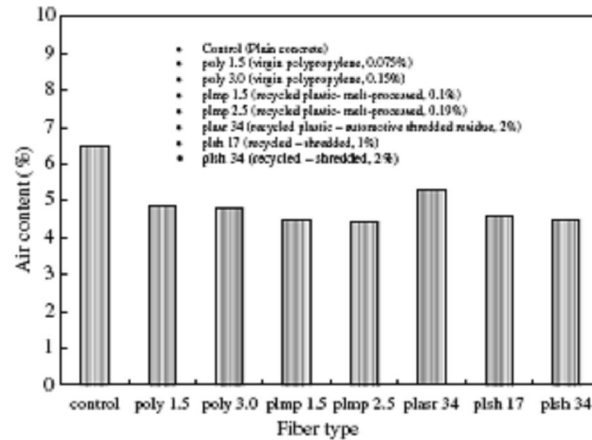


Fig. 2.7. Air content versus plastic fiber type (*Soroushian et al., 2003*).

2.4. UNIT WEIGHT

Khatib and Bayomy (1999) concluded that because of low specific gravity of rubber particles, unit weight of mixtures containing rubber decreases with the increase in the percentage of rubber content. Moreover, increase in rubber content increases the air content, which in turn reduces the unit weight of the mixtures. The decrease in unit weight of rubcrete is found to be negligible when rubber content is lower than 10–20% of the total aggregate volume.

2.5. HARDENED CONCRETE PROPERTIES

2.5.1. Compressive strength

Choi et al. (2005) studied the effects of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) on the compressive strength of concrete. Mixture proportions of concrete were planned so that the water–cement ratios were 45%, 49%, and 53%, and the replacement ratios of WPLA were 0%, 25%, 50%, and 75% by volume of fine aggregate. It is found that compressive strength of concrete mixtures decreased with the increase in PET aggregates and for a particular PET aggregate content, compressive strength increased with the reduction in w/cm ratio.

Batayneh et al. (2007) investigated the effect of ground plastic on the compressive strength of concrete. Concrete mixes of up to 20% of plastic particles are proportioned to partially replace the fine aggregates. They concluded that the addition of plastic particles led to a reduction in the strength properties. For a 20% replacement, the compressive strength exhibited a sharp reduction of up to 72% of the original strength. With 5% replacement, the compressive strength showed a 23% reduction. This reduction in strength was due to the fact that the strength of the plastic particles is lower than that of the aggregate. They concluded that both the use of concrete with plastic particles and the percentage of replacement should be controlled, according to the allowable strength of the structural element to be constructed.

Marzouk (2007) studied the innovative use of consumed plastic bottle waste as sand-substitution aggregate within composite materials for building application. Bottles made of polyethylene terephthalate (PET) were used as partial and complete substitutes for sand in concrete composites. Various volume fractions of sand varying from 2% to 100% were substituted by the same volume of granulated plastic, and various sizes of PET aggregates. They concluded that substituting sand at a level below 50% by volume with granulated PET, whose upper granular limit equals 5 mm, affected the compressive strength of composites and plastic bottles shredded into small PET particles may be used successfully as sand-substitution aggregates in cementitious concrete composites. These composites appeared to offer an attractive low-cost material with consistent properties; moreover, they would help in resolving some of the solid waste problems created by plastics production and in saving energy.

Bayasi and Zeng (1993) reported the effects of polypropylene fibers on the compressive strength of concrete. The compressive behavior characteristics of concrete are studied in terms of compressive strength and toughness index. Compressive toughness index is defined as the total compressive energy absorbed (total area under compressive stress–strain curve) divided by the pre-peak compressive energy absorbed (area under the stress–strain diagram up to peak stress). The test results are shown in [Fig.2.8](#) and

Table 2.4 (Siddique, 2007). It was concluded that 19 mm fibrillated polypropylene fibers had no obvious effect on the compressive strength of concrete. However, 19 mm fibrillated polypropylene fibers enhanced the energy absorption and toughness characteristics of concrete under compression, as evidenced by increase in compressive toughness index of concrete with fiber addition.

Table 2.4 Compressive strength of Hardened concrete (Choi et al., 2005)

w/cm ratio	PET aggregate (%)	Compressive strength (MPa)		
		3 days	7 days	28 days
53	0	18.4	24.0	3.27
	25	17.6	23.4	2.65
	50	17.1	21.5	2.25
	75	14.8	19.2	2.04
49	0	19.0	27.8	3.27
	25	18.8	26.7	2.76
	50	18.6	24.3	2.35
	75	15.8	21.6	1.94
45	0	24.8	31.3	3.32
	25	23.2	27.4	2.80
	50	22.0	26.5	2.55
	75	20.7	24.8	2.04

Marzouk et al (2007) has presented that the variations in the compressive strength of composites as a function of the volumetric percentage of recycled aggregate substitutes used. It can initially be seen, that once the sand volume substituted with aggregates increased from 0% to 50%, the compressive strength of composites decreased slightly, by 15.7% in comparison with the reference mortar. However, these various values are higher than the 28-day compressive strengths obtained in previous works (Vaverka, 1991)

Batayneh et al. (2007) demonstrated in their study that the addition of the plastic particles led to a reduction in the strength properties. For a 20% replacement, the compressive strength shows a sharp reduction up to 72% of the original strength. With 5% replacement the compressive strength shows a 23% reduction as shown in Fig.2.9.

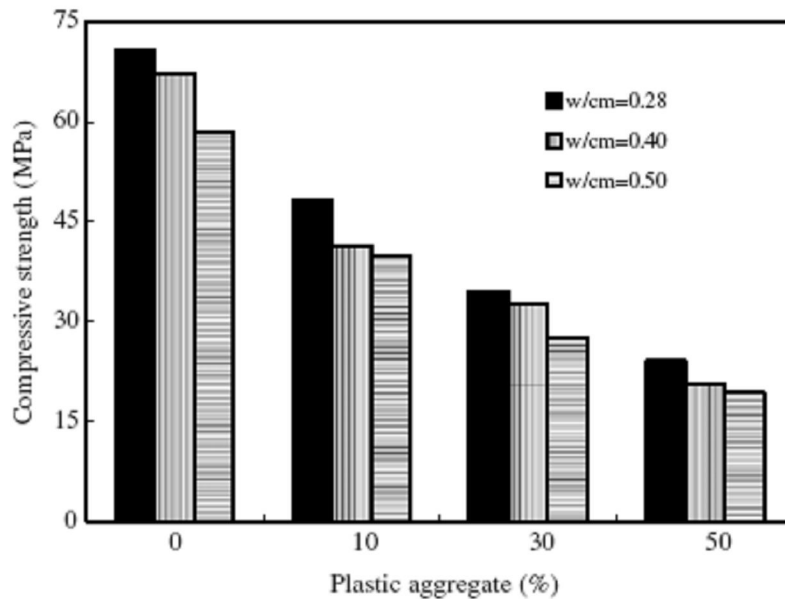


Fig.2.8. Compressive strength versus plastic fiber percentage (*Al-Manaseer and Dalal, 1997*)

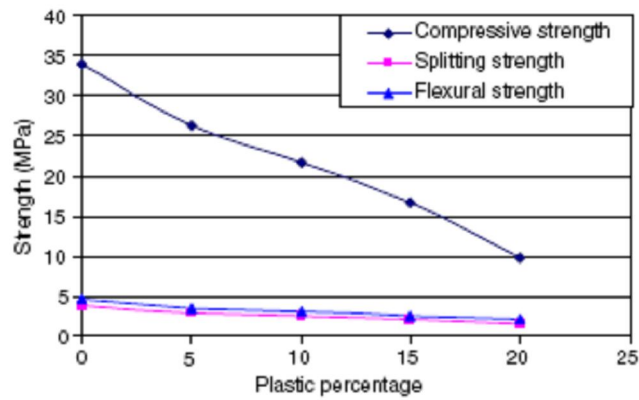


Fig.2.9. Relationship between the compressive strength and percentage of plastic content (*Batayneh et al., 2007*)

Babu et al. (2004) concluded that compressive strength showed an increasing trend as the age increases and also the percentage of increase in almost all the mixes at 7 days to 28 days and 28 days to 90 days was even higher than 35%. The strength decreases with the increase of EPS (expanded plastics) percentage (i.e., varying linearly with the density of the concrete) as shown in Fig.2.10.

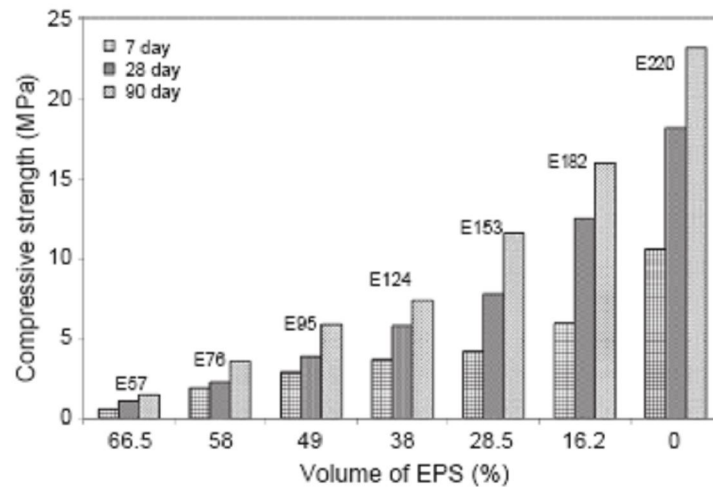


Fig. 2.10. Variation of compressive strength with age and EPS volume (*Babu et al., 2004*)

Jo et al. (2007) studied the effect of recycled aggregates and resins on compressive strength of concrete. In recycled-PET polymer concrete with recycled concrete aggregates (RPC), a gradual reduction in strength was observed as the recycled aggregate content increased. This effect was due to the weaker bond of the old mortar adhering to the recycled concrete aggregate, which may have caused a reduction in the strength of the RPC. Studying the influence of resin on properties of concrete, it was observed that the compressive strength of RPC increased with resin content. However, beyond certain resin content (approximately 13–17% resin) the strength did not change appreciably with increasing resin content. The increase in strength with the use of resin was due to the voids in the old mortar attached to the recycled aggregate

Ghaly et al. (2004) conducted research on plastic chips that were used as partial replacement of coarse aggregates in concrete mixtures. In this study, plastic aggregates

replaced 5, 10 and 15% by mass of coarse aggregates. It was found that for a given w/c ratio, the greater the plastic content in the mix, the lower is the compressive strength of concrete. Digital imaging of concrete cube sections with plastics showed that the plastics were well dispersed in the concrete. It also revealed that the reduction in compressive strength is directly proportional to the area of plastic chips in the section as given in Table.2.5.

Table 2.5 Percent Reduction in Compressive Strength versus Percent Plastics for Different w/c (Ghaly et al., 2004)

w/c	Percent plastics	% average area plastics	% reduction in compressive strength
0.42	5	4.95	14.75
0.42	10	8.54	18.04
0.42	15	11.69	28.64
0.54	5	4.25	6.37
0.54	10	7.59	20.37
0.54	15	10.52	29.28
0.69	5	5.02	15.17
0.69	10	10.87	18.65
0.69	15	15.48	34.78

Eldin et al (1993) compared the use of rubber as coarse aggregates and the use of rubber chips as sand. The reductions of up to 85% of the compressive strength were observed when the coarse aggregate was replaced by rubber. A smaller reduction in compressive strength (65%) was observed when sand was replaced by crumb rubber. It was further observed that rubber-containing concrete did not exhibit brittle failure under compression. The strength reduction can be attributed both to a reduction of the quantity of the solid load-carrying material and to stress concentrations (tensile and compressive) in the paste at the boundaries of the rubber aggregate. Also, no major change in compressive strength of concrete was observed when the tests are conducted at the age of 7 days and 28 days, as shown in Fig. 2.11.

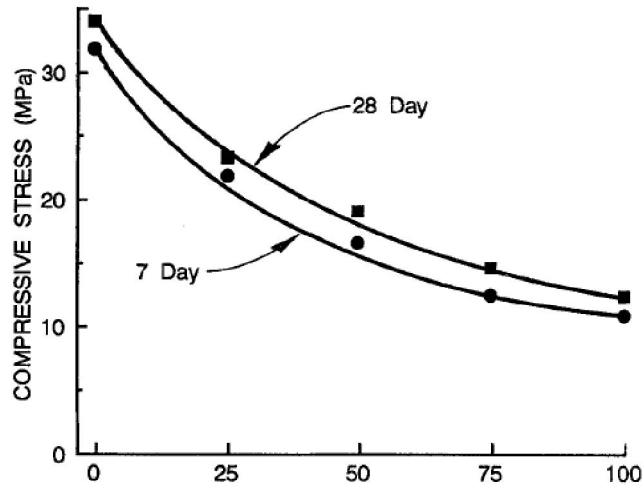


Fig.2.11. Compressive Strength for Group 2 Specimens (Eldin et al., 1993)

Naik et al. (1996) investigated the effect of post-consumer waste plastic in concrete as a soft filler. Their test results showed lower compressive strength of the mix made with plastics than the reference mixture without plastic (Fig.2.12). This was attributed to lower compressive strength of the plastic particles compared to cementitious matrix as well as natural fine and coarse aggregates. The effect of various treatments on plastics was also studied and it was concluded that out of the three treatments used on the plastics, alkaline bleach treatment is best with respect to compressive strength of concrete.

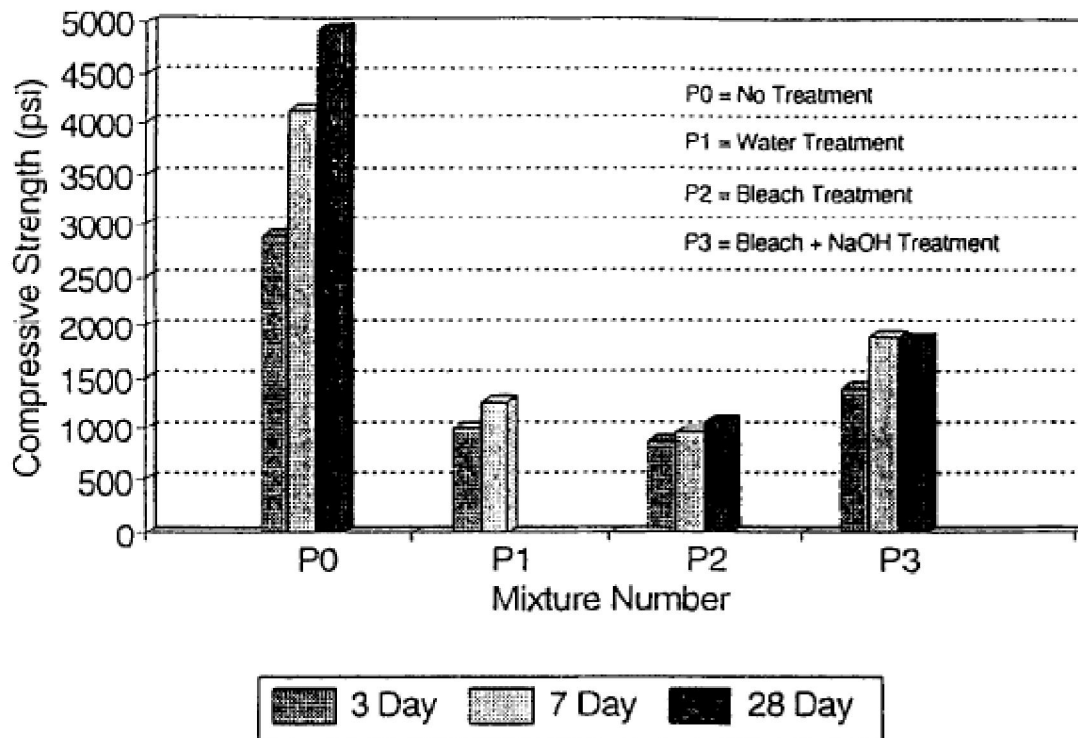


Fig.2.12. Effect of treatment on compressive strength of concrete (Naik et al., 1996)

2.5.2 Tensile strength

2.5.2.1. Split tensile strength

Al-Manaseer and Dalal (1997) studied the effects of plastic aggregates on the splitting tensile strength of concrete. The split tensile strength of concrete was measured at different water-to-binder ratios and for various percentages of plastic aggregates, as shown in Fig. 2.13 It was concluded that the splitting tensile strength decreased with the increase in plastic aggregates percentage (the splitting tensile strength was found to decrease by 17% for concrete containing 10% plastic aggregates). For a given plastic aggregate content, the splitting tensile strength was found to decrease when w/c ratio was increased. It was also observed that the splitting failure of concrete specimens containing plastic aggregates did not exhibit the typical brittle failure observed in the case of conventional concrete. The splitting tensile failure was more of a gradual failure as was the case for specimens tested under compression load. In general, specimens containing

plastic aggregates were found to be more capable of resisting the splitting load after failure without full disintegration. The failure was found to be more ductile in nature when the percentage of plastic aggregates was increased.

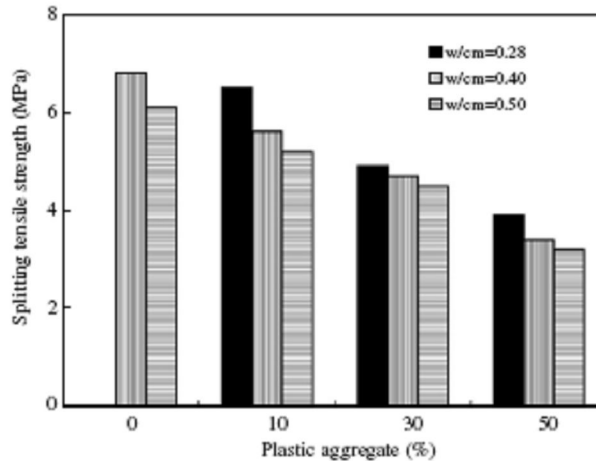


Fig.2.13. Splitting tensile strength versus plastic aggregate percentage (*Al- Manaseer and Dalal, 1997*)

Choi et al. (2005) studied the influence of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) on the splitting tensile strength of concrete. Mixture proportions of concrete were planned so that the water– cement ratios were 45%, 49%, and 53%, and the replacement ratios of WPLA were 0%, 25%, 50%, and 75% by volume of fine aggregate. Splitting tensile strength of concrete mixtures was observed to decrease with the increase in PET aggregates; and for a particular PET aggregate content, splitting tensile strength increased with the reduction in w/cm ratio

Batayneh et al. (2007) observed similar behavior, in splitting and flexural strengths of the tested samples. *Fig.2.14* shows that the reduction in strength is due to the fact that the strength of the plastic particles is lower than that of the aggregate. Therefore, both the use of concrete with plastic particles and the percentage of replacement should be controlled, according to the allowable strength of the structural element to be constructed

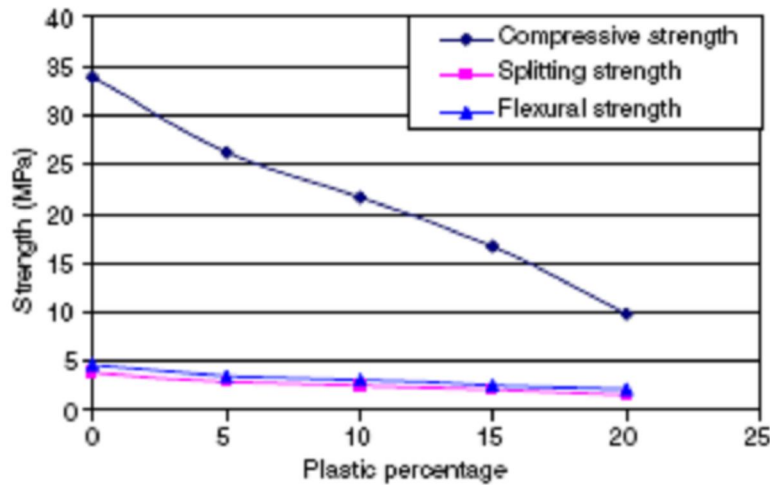


Fig.2.14. Relationship between the tensile strength and percentage of plastic content
(Batayneh et al., 2007)

Babu et al (2004) reported that the splitting tensile strength decreases with increase in the EPS (expanded plastic) volume percentage and with higher EPS(expanded plastic) concretes showed the gradual splitting whereas in the lower volume of EPS (expanded plastic) concretes the splitting was somewhat sudden, though not like normal concretes. The relation between compressive strength and split tensile strength was also developed as shown in Fig.2.15. The proposed equation ($r=0.995$) based on the results of these concretes is given by $f_t = 0.358f_c^{0.675}$

Jo et al. (2007) studied the effect of recycled aggregates and resins on tensile strength of concrete. In the case of split tensile strength they observed that there was a slight increase in the strength of RPC made with a resin content of 13% compared to RPC made with a resin content of 9%. This increase was predicted to be due to the different and complex failure mechanisms of the material in RPC under tension.

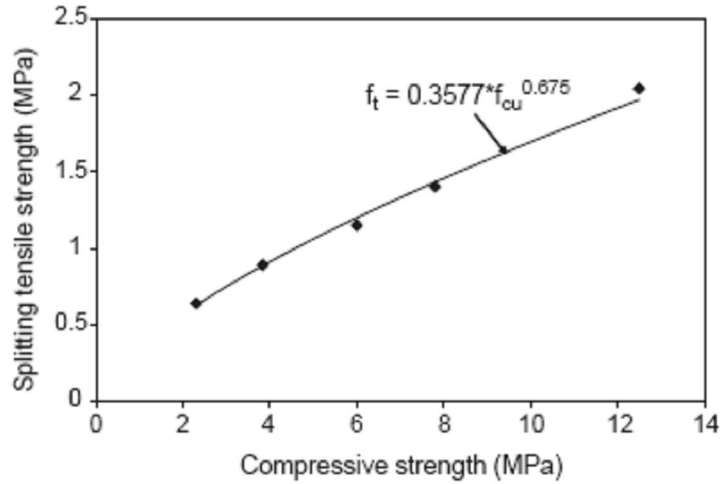


Fig.2.15. Variation of splitting tensile strength with compressive strength (*Babu et al., 2004*)

Eldin et al. (1993) determined the tensile strengths of a 35 MPa Portland-cement concrete were determined after replacing the aggregate and sand by rubber particles. Reductions up to 50% of the tensile strength were observed when the coarse aggregate was replaced by rubber. The strength reduction can be attributed both to a reduction of the quantity of the solid load-carrying material and to stress concentrations (tensile) in the paste at the boundaries of the rubber aggregate. Unlike compressive strength, tensile strength of concrete increased with the increase in age of concrete (*Fig. 2.16*).

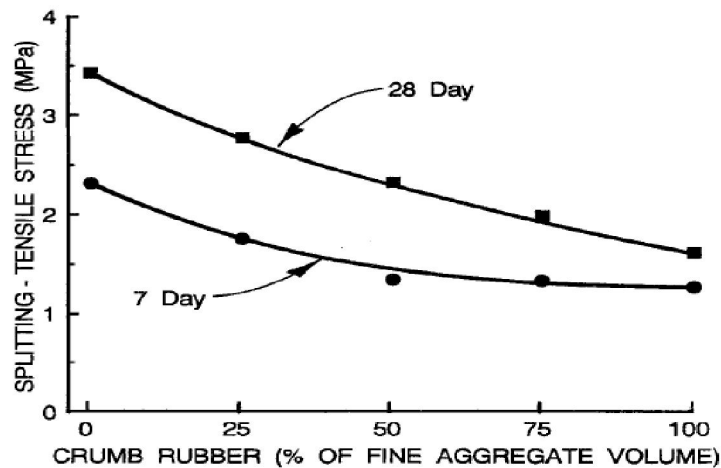


Fig. 2.16. Tensile Strength for Group 2 Specimens (*Eldin et al., 1993*)

2.5.2.2. Flexural strength of concrete

Marzouk et al. (2007) studied that the flexural strength of new composites decreases regularly as the volume of PET (expanded plastic) recycled aggregate increases as given below in Fig 2.17

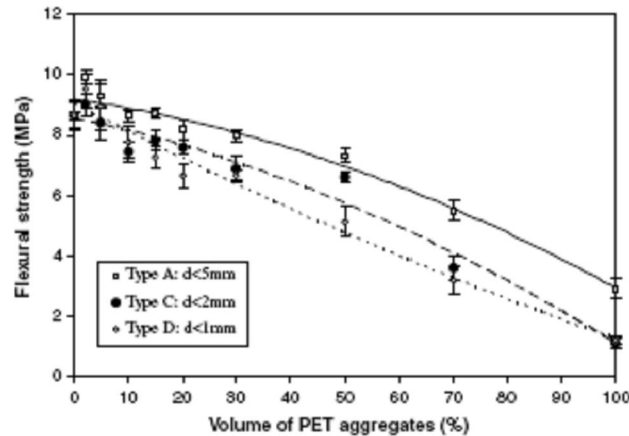


Fig.2.17. Effect of PET-recycled aggregates on the flexural strength of the composites. (*Marzouk et al.,2007*)

Choi et al. 2005) found that the flexural strength of new composites decreases regularly with the increase in percentage of plastics in concrete. For 50% replacement of aggregates by plastics, the flexure strength reaches 32.8% of the reference concrete.

2.5.3. Modulus of elasticity

Al-Manaseer and Dalal (1997) reported the effects of plastic aggregates on the modulus of elasticity of concrete. Fig.2.18 shows the results of modulus of elasticity of concrete containing different percentages of plastic aggregates. They concluded that the value of modulus of elasticity decreased with the increase in plastic aggregate content. Depending upon w/c ratio, modulus of elasticity was found to vary between 24.3 GPa for concrete containing no aggregates (w/c = 0.28) to 8.6 GPa for concrete containing 50% plastic aggregates (w/c = 0.50). In general, increase in w/c ratio decreased the modulus of elasticity of concrete.

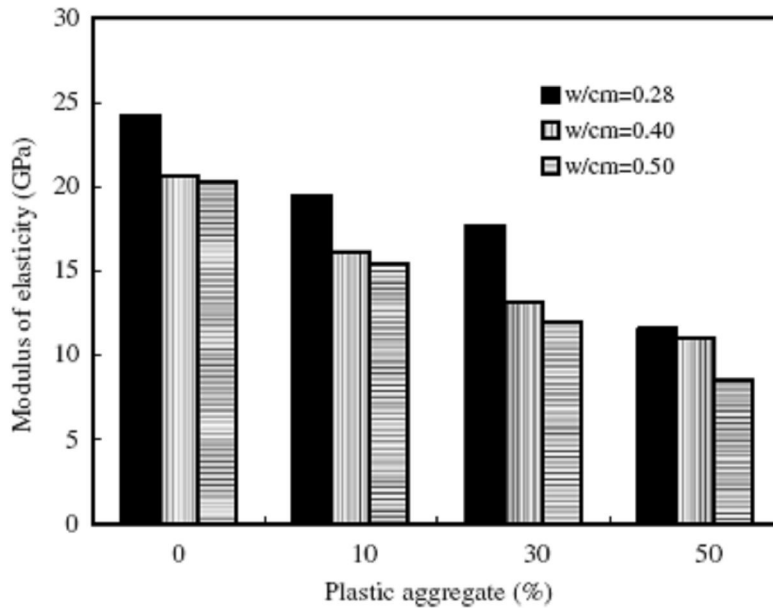


Fig.2.18. Modulus of elasticity versus plastic fiber percentage (Al-Manaseer and Dalal, 1997)

Choi et al. (2005) investigated the effect of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) on the modulus of elasticity of concrete. Mixture proportions of concrete were planned so that the water–cement ratios were 45%, 49%, and 53%, and the replacement ratios of WPLA were 0%, 25%, 50%, and 75% by volume of fine aggregate. As can be observed from [Table 2.6](#) It is clear that modulus of elasticity of concrete mixtures decreases with the increase in percentage of aggregates.

Marzouk et al. (2007) also observed that modulus values decrease as PET quantity increases ([Fig.2.19](#)) has shown. For example, at a 50% substitution rate, a 50% reduction of modulus of elasticity was noted, in comparison with the reference mortar .Reduction in modulus of elasticity is due both to the reduction of composite bulk densities and to plastic aggregates, which decrease the celerity of wave by disturbing the ultrasonic wave propagation. This finding indicates the positive influence from substituting siliceous aggregates with plastic aggregates on the durability of mortar and its behavior with vibrations.

Table 2.6. Hardened concrete properties (*Choi et al., 2005*)

w/cm ratio	PET aggregate (%)	Modulus of elasticity (MPa)
53	0	23.5
	25	23.0
	50	21.2
	75	18.5
49	0	23.3
	25	22.8
	50	18.1
	75	16.7
45	0	25.5
	25	18.7
	50	17.3
	75	15.6

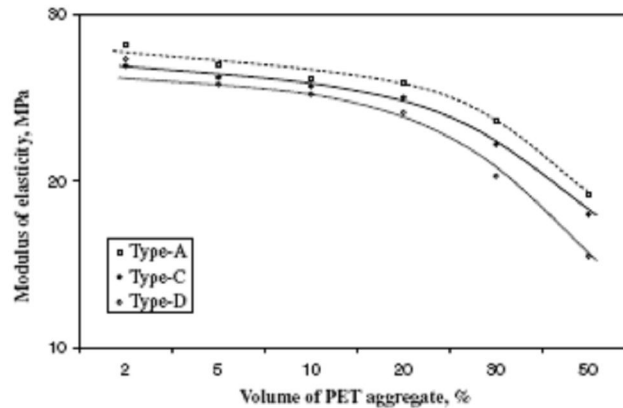


Fig.2.19. Modulus of elasticity of composites vs. volume of PET aggregate (*Marzouk et al., 2007*)

Jo et al. (2007) observed that the elastic modulus of RPC at 7 days decreased similarly to its compressive strength, suggesting that there may be a correlation between the compressive strength and the elastic modulus of RPC. (*Babu et al., 2004*) developed a relation between compressive strength and modulus of elasticity of concrete. Fig.2.20 shows the relationship between modulus of elasticity and compressive strength. The modulus of elasticity values was found to increase with an increase in the compressive

strength and decreased with increase in percentage volume of EPS (expanded plastic). The secant modulus value was seen to be decreasing and this decrease was found to be about 40% for every 10% increase in the EPS (expanded plastic) volume.

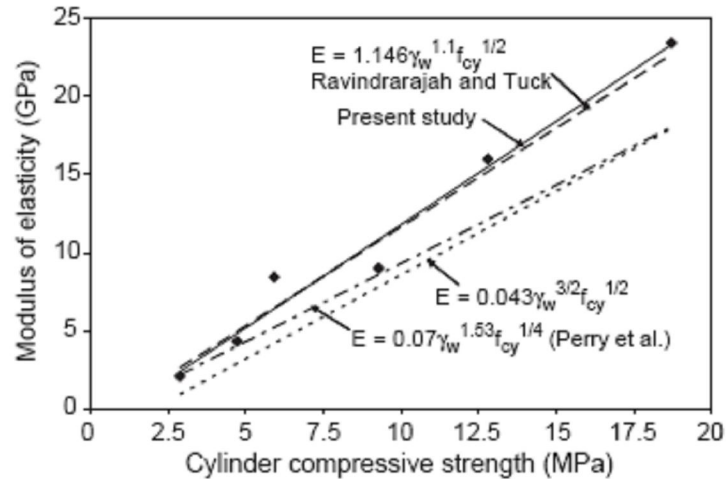


Fig. 2.20. Relationship between modulus of elasticity and compressive strength (Jo et al, 2007)

Ghaly et al.(2004) concluded that for a given water-cement ratio, the modulus of elasticity decreases with the increase in plastic content in the mix. Relationship between modulus of elasticity and percentage of plastics was developed. Fig.2.21 shows the relationship between the modulus of elasticity and the percent of plastics in the concrete mix for the three w/c 's tested. This figure shows a general trend where the value of the modulus decreases with the increase of the percent plastics in the mix. Fig.2.22 shows the relationship between the percent reductions in the modulus of elasticity versus the percent of average area of plastics in a concrete cross section. An exponential curve was found to best fit the data.

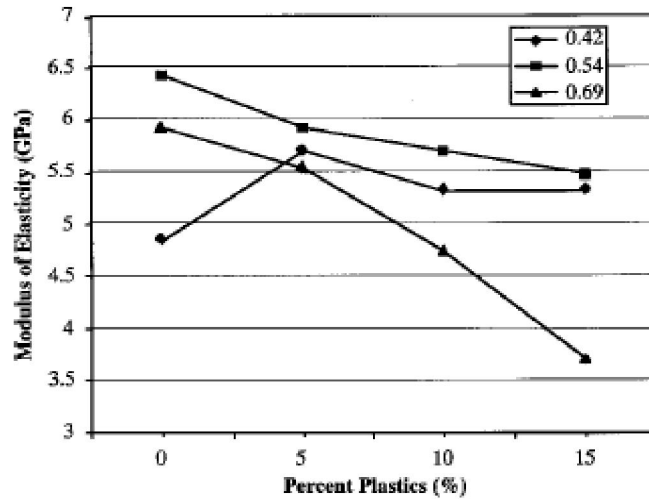


Fig.2.21. Relationship of modulus of elasticity and percent plastics (*Ghaly et al., 2004*)

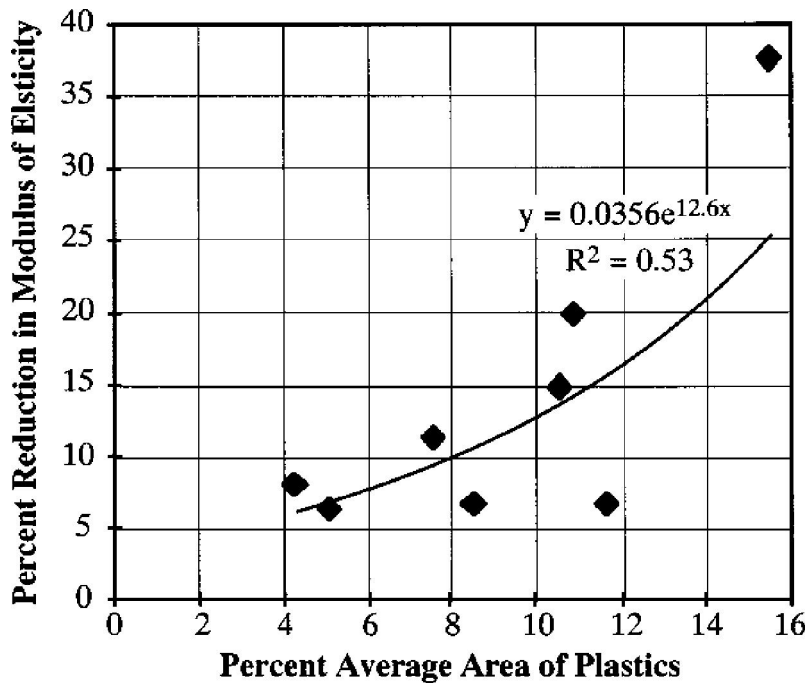


Fig.2.22. Relationship of percent reduction in modulus of elasticity and percent average area of plastics (*Ghaly et al., 2004*)

2.6. OTHER PROPERTIES OF CONCRETE

2.6.1. Freezing and thawing resistance

Savas et al. (1996) carried out investigations to study the rapid freezing and thawing durability of rubber concrete. Various mixtures were made by incorporating 10%, 15%, 20% and 30% ground rubber by weight of cement used for the control mixture. Based on their studies, they concluded that: (i) rubcrete mixtures with 10% and 15% ground rubber (2–6 mm in size) exhibited durability factors higher than 60% after 300 freezing and thawing cycles, but mixtures with 20% and 30% ground rubber by weight of cement could not meet the ASTM standards (durability factor); (ii) air-entrainment did not provide improvements in freezing and thawing durability for concrete mixtures with 10%, 20% and 30% ground tire rubber and (iii) increase in scaling (scaling gives an evaluation of the surface exposed to freezing and thawing cycles as measured by the loss of weight) increased with the increase in freezing and thawing cycles

Benazzouk and Queneudec (2002) studied the freeze– thaw durability of cement–rubber composites through the use of two types of rubber aggregates. They used the two types of the aggregates: compact rubber aggregate (CRA) and expanded rubber aggregates (ERA). Volume-ratio of the aggregates ranged from 9% to 40%. The results showed improvements in the durability of the composite containing 30% and 40% rubber by volume. Improvement in the durability of the composite containing ERA type aggregates is better than composite made with (CRA) compact rubber aggregate aggregates. The finding is more distinct for expanded rubber aggregates (ERA) type. *(Paine et al., 2002)* investigated the use of crumb rubber as an alternative to air-entrainment for providing freeze–thaw resisting concrete. Their test results showed that there is potential for using crumb rubber as a freeze–thaw resisting agent in concrete. The crumb rubber concrete performed significantly better under freeze–thaw conditions than plain concrete, and the performance of crumb rubber concrete in terms of scaling was similar to that of air-entrained concrete.

2.6.2. Shrinkage.

Raghvan et al. (1998) reported that the incorporation of rubber shreds (two different shapes of rubber particles as constituents of mortar help in reducing plastic shrinkage cracking in comparison to control mortar. They further reported that control specimens developed cracks having an average width of about 0.9 mm, while the average crack width for specimens with a mass fraction of 5% rubber shreds was about 0.4–0.6 mm. It was also reported that onset time of cracking was delayed by the addition of 5% rubber shreds.

2.6.3. Toughness

It is known as energy absorption capacity and is generally defined as the area under load–deflection curve of a flexural specimen.

Tantala et al. (1996) investigated the toughness of a control concrete mixture and rubcrete mixtures with 5% and 10% buff rubber by volume of coarse aggregate. They reported that toughness of both rubcrete mixtures was higher than the control concrete mixture. However, the toughness of rubcrete mixture with 10% buff rubber (2–6 mm) was lower than that of rubcrete with 5% buff rubber because of the decrease in compressive strength.

Khatib and Bayomy (1999) reported that as the rubber content is increased, rubcrete specimens tend to fail gradually and failure mode shape of the test specimen is either a conical or columnar (conical failure is gradual, whereas columnar is more of shreds having two sizes which were, nominally, 5.5 mm-1.2 mm and 10.8 mm-1.8 mm (length diameter) sudden failure). At a rubber content of 60%, by total aggregate volume, the specimens exhibited elastic deformations, which the specimens retained after unloading. *(Eldin and Senouci, 1993)* demonstrated that the failure mode of specimens containing rubber particles was gradual as opposed to brittle.

Biel and Lee (1996) reported that failure of concrete specimens with 30%, 45% and 60% replacement of fine aggregate with rubber particles occurred as a gradual shear that resulted in a diagonal failure, whereas failure of plain (control) concrete specimens was explosive, leaving specimens in several pieces.

Goulias and Ali (1997) found that the dynamic modulus of rigidity decreased with an increase in the rubber content, indicating a less stiff and less brittle material. They further reported that dampening capacity of concrete (a measure of the ability of the material to decrease the amplitude of free vibrations in its body) seemed to decrease with an increase in rubber content.

However, *Topcu and Avcular (1997)* have recommended the use of rubberized concrete in circumstances where vibration damping is required. Similar observations were also made by *(Fattuhi and Clark, 1996)* Reported that the impact resistance of concrete increased when rubber aggregates were incorporated into the concrete mixtures. The increase in resistance was derived from the enhanced ability of the material to absorb energy.

Hernandez-Olivares et al. (2002) have reported that addition of crumb tire rubber volume fractions up to 5% in a cement matrix does not yield a significant variation of the concrete mechanical features, either maximum stress or elastic modulus

2.6.4. Impact resistance

Bayasi and Zeng (1993) investigated the influence of polypropylene fibers on the impact resistance of concrete. They concluded that polypropylene fiber enhanced the impact resistance of concrete significantly. This was especially true for 12.7 mm long fibers. These fibers significantly increased the impact resistance of concrete for volumes that do not affect mix workability (less than 0.5%), while, at higher volume contents, impact resistance may tend to decrease.

Soroushian et al. (2003) studied the effect recycled plastic on the impact resistance of concrete. The impact test involved repeated dropping of a standard hammer from a particular height until a 63.5 mm concrete cylinder with a 152.4 mm diameter exhibited failure (*Balaguru and Shah., 1992*). Different fibers provided different geometric, bond, and stiffness characteristics, which explains rather significant differences observed in the improvements in impact resistance brought about by different fiber reinforcement systems.

2.6.5. Abrasion resistance

Soroushian et al. (2003) investigated the effect of recycled plastic on the abrasion resistance of concrete. The abrasion test results are shown in [Fig. 2.23](#). Most discrete reinforcement systems were observed to cause some reduction of the abrasion resistance of concrete (reflected in increased mass loss in the presence of fibers). This effect could result from the fact that fibers occurring near the surface could debond under abrasion effects, thereby contributing to mass loss; change in the bleeding characteristics of concrete in the presence of fibers could also modify surface characteristics of concrete and thus its abrasion resistance.

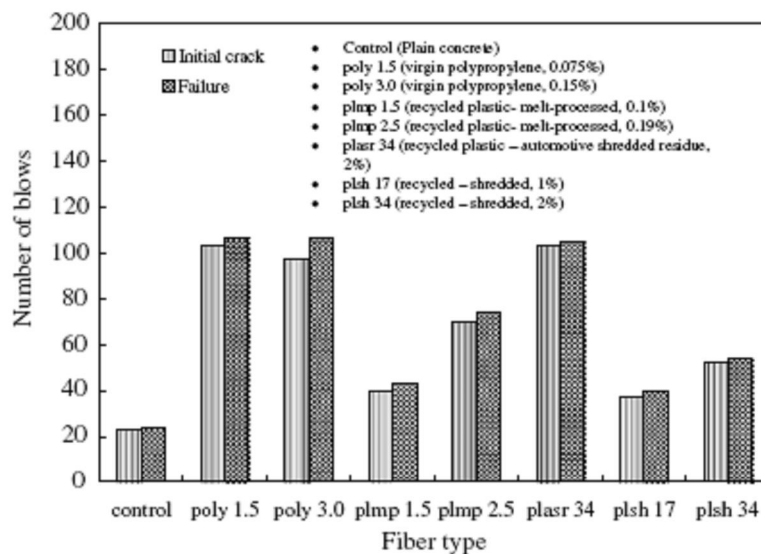


Fig.2.23. Impact resistance versus fiber type (*Soroushian et al., 2003*)

2.6.6. Permeability

Bayasi and Zeng (1993) investigated the effect of recycled plastic on the permeability of concrete. They concluded that 19-mm polypropylene fibers significantly increased the permeability of concrete with an inconsistent effect on the volume fraction of permeable voids; 12.7-mm long fibers somewhat increased the permeability of concrete and tend to decrease the volume of permeable voids.

Soroushian et al. (2003) demonstrated that there was decrease in air permeability with the inclusion of discrete reinforcement in concrete. The air permeability test as shown in Fig.2.24 measured the rate of air through a concrete specimen. Lower airflow rates are preferable, indicating lower permeability. Discrete reinforcement systems were used in the project to reduce permeability of concrete, which could be attributed to reduced shrinkage micro-cracking. Reduced permeability favors long-term durability of concrete systems incorporating discrete reinforcement.

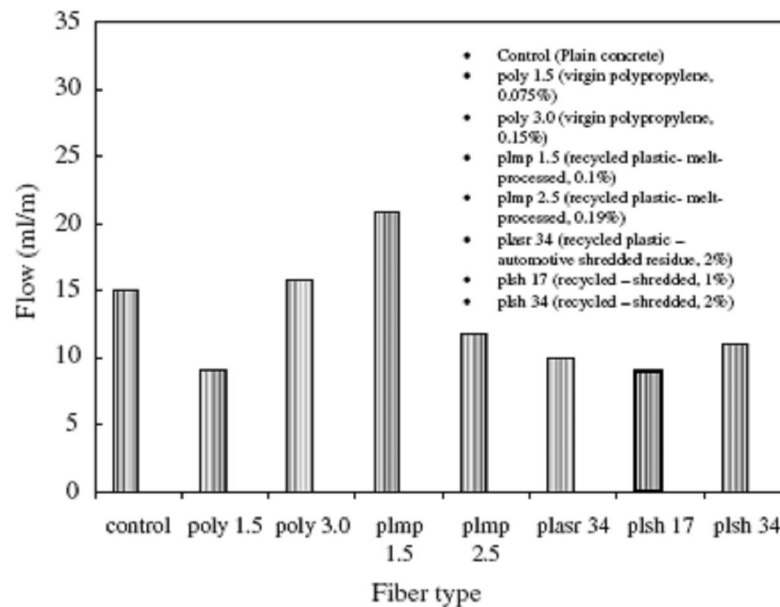


Fig.2.24. Air permeability versus fiber type (*Soroushian et al., 2003*)

2.6.7. Shrinkage of concrete

Marzouk et al. (2007) in this research, the study of the durability was based on the study of various factors like sorptivity, sorption in gaseous phase, shrinkage under conditions of complete saturation and modulus of elasticity. The coefficient of sorptivity, which reflects the facility of water penetration into the composite, varies from 0.0136 to 0.0014 $\text{cm}^3/\text{cm}^2 \text{ s}^{1/2}$ for a substitution of 50% by volume (*Yazoghli-Marzouk et al., 2005*). The non-sorptivity property of PET inclusions contributed to slow down the propagation of the imbibitions' front by forcing the hydrous flow to bypass them i.e. by increasing tortuosity. When the dry mortars were maintained in a temperature- controlled room under saturated atmosphere (100% relative humidity and $20 \text{ }^\circ\text{C} \pm 2$), experimental results reveal that a volumetric substitution lower than 100% decreases the rate of adsorption with respect to the reference mortar that contains no waste. The various rates of adsorption are lower than 6%. The coefficient of sorptivity can be 10 times weaker and the rates of adsorption are weak, this prominently highlights the durability present in the case of contact with water containing aggressive agents. The study of shrinkage under conditions of complete saturation (see Fig.2.25) shows that once the sand volume substituted with waste aggregates increases from 0% to 30%, the plastic aggregates do not exert an influence on shrinkage of composites in comparison with the reference mortar.

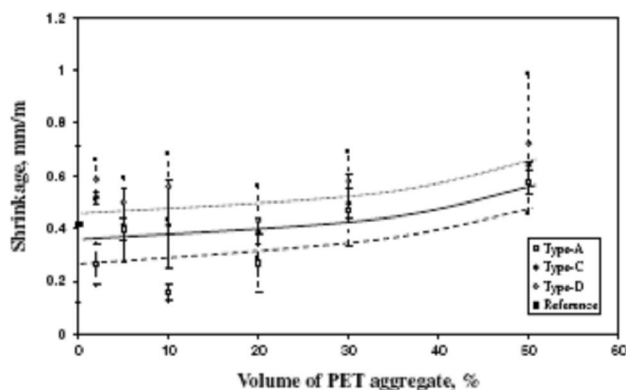


Fig.2.25. Shrinkage of composites under conditions of complete saturation (*Marzouk et al., 2007*)

2.6.8. Acid and alkali resistance

Jo et al. (2007) in acid resistance testing, RPC with a resin content of 9% was found to be nearly unaffected by HCl, whereas RPC with 100% recycled aggregate showed poor acid resistance. According to the evidence from weight change and compressive strength, alkali, unlike acid, did not seem to attack RPC

CHAPTER 3

EXPERIMENTAL PROGRAMME

3.1. GENERAL

The aim of the experimental program is to compare the properties of concrete made with and without plastics, used as coarse aggregates. The basic tests carried out on materials used for casting concrete samples are discussed in this chapter, followed by a brief description about mix design and curing procedure adopted. At the end, the various tests conducted on the specimens are discussed.

3.2. MATERIALS USED

3.2.1. Cement

Cement is a fine, grey powder. It is mixed with water and materials such as sand, gravel, and crushed stone to make concrete. The cement and water form a paste that binds the other materials together as the concrete hardens. The ordinary cement contains two basic ingredients namely argillaceous and calcareous. In argillaceous materials clay predominates and in calcareous materials calcium carbonate predominates. Basic composition of cement are shown in [Table 3.1](#).

Table 3.1 Composition limits of Portland cement

Ingradient	% Content
CaO(Lime)	60-67
SiO ₂ (Silica)	17-25
Al ₂ O ₃ (Alumina)	3-8
Fe ₂ O ₃ (Iron Oxide)	0.5-6
MgO(Magnesia)	0.1-4
Alkalies	0.4-1.3
Sulphur	1-3

Grade 53 Ultra Tech cement was used for casting cubes and cylinders for all concrete mixes. The cement was of uniform colour i.e. grey with a light greenish shade and was free from any hard lumps. Summary of the various tests conducted on cement are as under given below in [Table 3.2](#).

Table 3.2 Properties of cement

S.No.	Characteristics	Values obtained	Standard values
1.	Normal Consistency	33%	-
2.	Initial Setting time	48 min	Not be less than 30 minutes
3.	Final Setting time	240 min	Not be greater than 600 minutes
4.	Fineness	4.8 %	<10
5.	Specific gravity	3.09	-
<i>Compressive strength:- Cement : Sand (1:3)</i>			
1.	3 days	24.5 N/mm ²	27 N/mm ²
2.	7 days	35 N/mm ²	41 N/mm ²
3.	28 days	53.5 N/mm ²	53 N/mm ²

3.2.2. Fine Aggregates

The sand used for the experimental programme was locally procured and conformed to Indian Standard Specifications IS: 383-1970. The sand was first sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and then was washed to remove the dust. Properties of the fine aggregate used in the experimental work are tabulated in [Table 3.3](#). The aggregates were sieved through a set of sieves as shown in [Fig. 3.1](#) to obtain sieve analysis and the same is presented in [Table 3.4](#). The fine aggregated belonged to grading zone III.

3.2.3. Coarse aggregates

The material which is retained on BIS test sieve no. 480 is termed as a coarse aggregate. The broken stone is generally used as a coarse aggregate. The nature of work decides the maximum size of the coarse aggregate. Locally available coarse aggregate having the maximum size of 20 mm was used in our work. The aggregates were washed to remove

dust and dirt and were dried to surface dry condition. The aggregates were tested per Indian Standard Specifications IS: 383-1970. The results of various tests conducted on coarse aggregate are given in Table 3.5 and Table 3.6 shows the sieve analysis results. Plate 3.1 shows the sieve shaker apparatus used for the sieve analysis of aggregates

Table 3.3 Properties of fine aggregates

S. No.	Characteristics	Value
1.	Type	Uncrushed (natural)
2.	Specific gravity	2.68
3.	Total water absorption	1.02 %
4.	Fineness modulus	2.507
5.	Grading zone	III

Table 3.4 Sieve analysis of fine aggregate

S. No.	Sieve No.	Mass Retained (gms)	% Retained	% Passing	Cumulative %age Retained
1.	4.75 mm	95.0	9.5	90.5	9.5
2.	2.36 mm	42.5	4.25	86.25	13.75
3.	1.18 mm	110.5	11.05	75.2	24.8
4.	600 μ m	128.5	12.85	62.35	37.65
5.	300 μ m	308.0	30.8	31.55	68.45
6.	150 μ m	281.0	28.1	3.45	96.55
7.	Pan	34.5	3.45	-	
				$\Sigma F =$	250.7

$$\text{Fineness Modulus of fine aggregate} = \Sigma F / 100 = 250.7 / 100 = 2.507$$



Plate.3.1. Sieve Shaker apparatus

Table 3.5 Properties of Coarse aggregates

S. No.	Characteristics	Value
1.	Type	Crushed
2.	Maximum size	20 mm
3.	Specific gravity (20 mm)	2.825
4.	Total water absorption (20 mm)	3.645 %
5..	Fineness modulus (20 mm)	7.68

Table 3.6 Sieve analysis of 20 mm aggregates

S. No.	Sieve No.	Mass Retained (gms) (kg)	% retained Retained, %	% passing Passing, %	Cumulative % retained
1.	80 mm	-	0.00	100	0.00
2.	40 mm	-	0.00	100	0.00
3.	20 mm	0	0.00	100	0.00
4.	12.5 mm	2.1865	72.883	27.117	72.883
5.	10 mm	0.6745	22.483	4.634	95.366
6.	4.75 mm	0.1390	4.633	0.01	99.999
11.	Pan	0	0.00	-	-
				$\Sigma C =$	268.244

Fineness Modulus of Coarse aggregate (20mm) = $\Sigma C + 500 / 100 = 7.68$

3.2.4. Plastics Aggregates

Recycled plastic was used to replace coarse aggregates for making concrete specimens. These aggregates were available in three different sizes as shown in [Plate. 3.2](#). The sieve analysis of these aggregates were carried out individually and is presented in [Table 3.7](#), [Table 3.8](#) and [Table.3.9](#) for coarse, medium and small size aggregates, respectively.

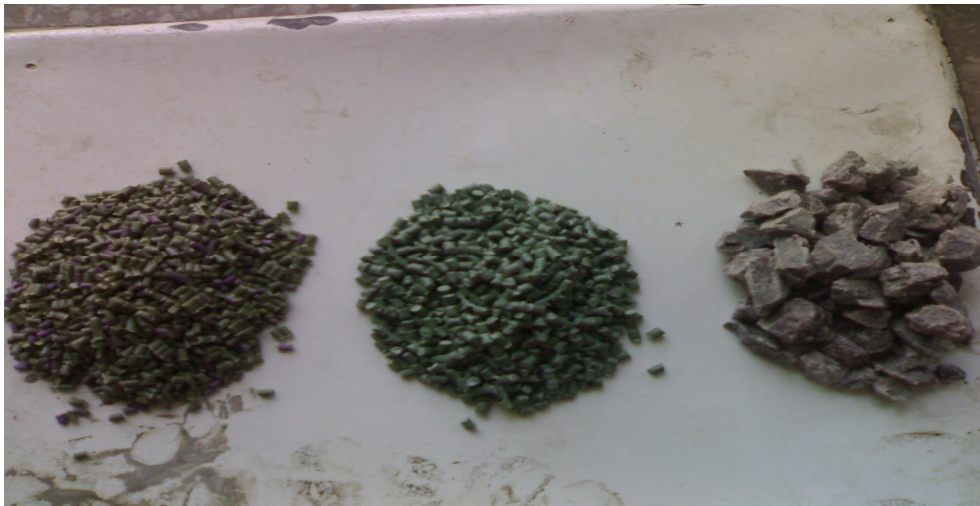


Plate.3.2. Three types of plastic aggregates (smaller, medium and coarser size)

Table 3.7 Coarse aggregate (Bigger size plastic aggregate - PB)

S.No.	Sieve No.	Mass Retained (gms)	% Retained	% Passing	Cumulative % Retained
1.	20mm	0	0.00	100	0.00
2.	12.5mm	292.5	21.35	78.65	21.35
3.	10mm	398.0	29.06	70.94	50.41
4.	5.6mm	510.0	37.23	62.77	87.64
5.	Pan	169.00	12.34	87.66	99.98

Fineness Modulus of bigger sized plastic aggregate = $\Sigma C+500/100 = 7.59$

Table 3.8 Coarse aggregate (Medium sized plastics aggregates - PM)

S. No.	Sieve No.	Mass	percentage Retained,%	Percentage Passing, %	Cumulative % age retained
1.	4.75 mm	4	0.8	99.2	0.8
2.	2.36 mm	487	97.4	2.6	98.2
3.	1.18 mm	9	1.8	98.2	100
4.	600 μ m	0	0	0	100
5.	300 μ m	0	0	0	100
6.	150 μ m	0	0	0	100
7.	Pan	0	0	-	

Fineness Modulus of medium sized plastic aggregate = $\Sigma C+500/100 = 9.99$

Table 3.9 Coarse aggregate (Smaller sized plastics aggregates - PS)

S. No.	Sieve No.	Mass Retained(gms)	percentage Retained,%	percentage Passing, %	Cumulative % age Retained
1.	4.75 mm	2	0.4	99.6	0.4
2.	2.36 mm	90	18	82	18.4
3.	1.18 mm	408	81.6	18.4	100
4.	600 μ m	0	0	0	100
5.	300 μ m	0	0	0	100
6.	150 μ m	0	0	0	100
7.	Pan	0	0	-	

Fineness Modulus of smaller sized plastic aggregate = $\Sigma C+500/100 = 9.18$

All the three aggregates were mixed together in a proportion so as to achieve maximum packing density. Packing density is defined as the ratio of the volume of plastic aggregates to the volume of equivalent water. For finding the volume of aggregates in a container, the mass of aggregates filled in the container is found and is divided by the specific gravity of the aggregates.

$$\text{Packing density} = \frac{\text{Volume of plastics aggregates}}{\text{Volume of equivalent water}}$$

$$\text{Volume of aggregates} = \frac{\text{Mass of plastic aggregates}}{\text{Specific gravity of aggregates}}$$

Specific gravity of the plastics aggregates = 1.1

For finding the maximum packing density of a combination of three different sizes of plastic aggregates, firstly, coarse and medium size aggregates are mixed together in various proportions and the corresponding packing density is noted. As the percentage of coarse aggregates is decreased and fine aggregates is increased, the packing density starts increasing, up to a certain point, then the packing density decreases with further increase in percentage of fine aggregates. The values of packing densities obtained after various trials are shown in [Table 3.10](#) and [Fig. 3.1](#). From the figure, it is clear that if combinations of big and medium size aggregates are used, the maximum packing density can be obtained by using a combination of 60% bigger size aggregates and 40% medium size aggregates. Further, 60% PB + 40% PM is used as base and to this combination, variable percentages of small size plastic aggregates (PS) are added, and the resultant packing density for each combination is obtained. The values of packing density are listed in [Table 3.11](#) and [Fig. 3.2](#). Hence, it can be seen that the maximum overall packing density can be achieved by using a combination of 60% (Big 60%+medium40%) + 40% small size.

Table 3.10 Coarser sized plastics aggregates and the medium sized plastics aggregates

Trials No.	Percentages of plastics aggregates		Packing density
	PB (%)	PM (%)	
1	100	0	0.543
2	90	10	0.547
3	80	20	0.555
4	70	30	0.564
5	60	40	0.568
6	50	50	0.565
7	40	60	0.564
8	30	70	0.555
9	20	80	0.558

Fig.3.1. Chart between packing density and Coarse sized aggregates (PB) + medium sized aggregates (PM)

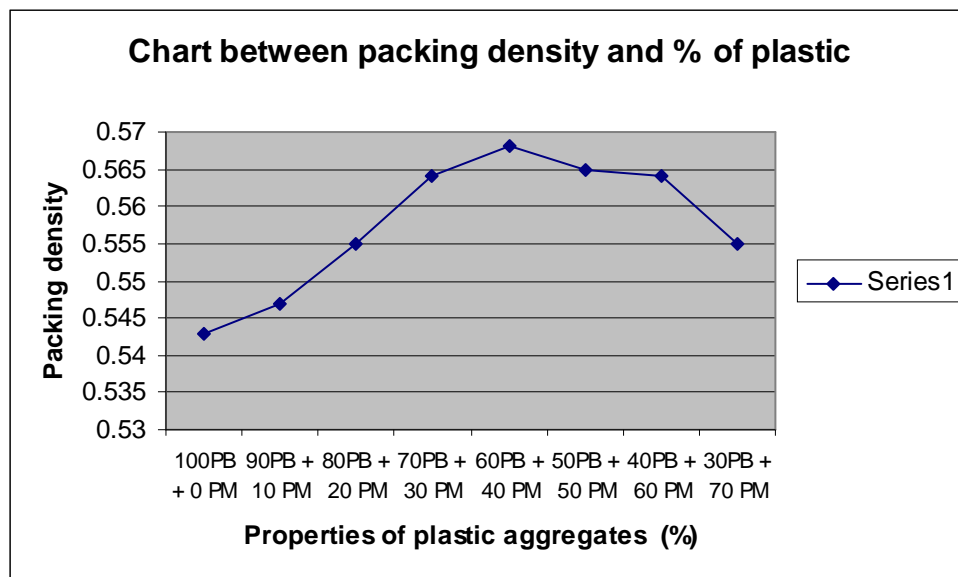


Table 3.11 Coarser sized plastics aggregates (60% PB+40%PM) and smaller sized plastics aggregates (PS)

Trials No.	Percentages of plastics aggregates		Packing density(kg/m ³)
	Coarse sized (60%PB+40 %PM)	Small size aggregate (%)	
1	100	0	0.568
2	90	10	0.574
3	80	20	0.581
4	70	30	0.583
5	60	40	0.590
6	50	50	0.589
7	40	60	0.596
8	30	70	0.592
9	20	80	0.591

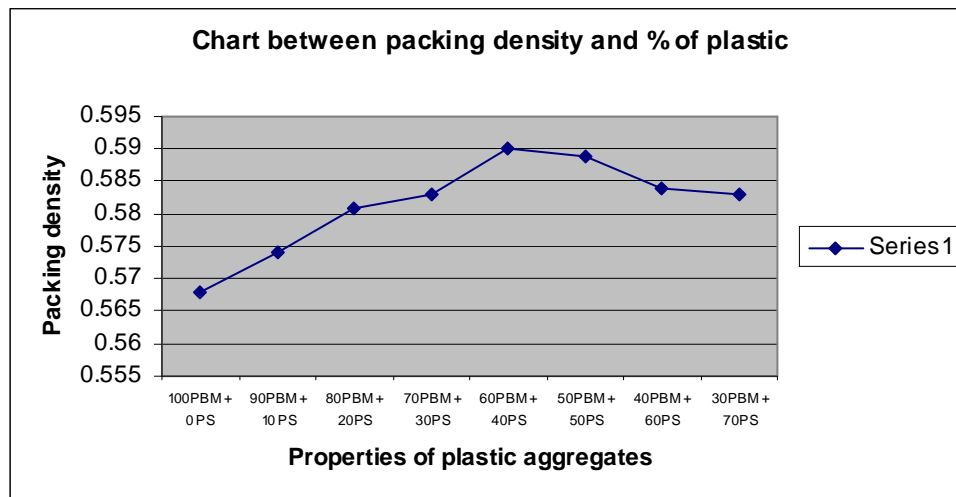


Fig.3.2. Chart between packing density (kg/m³)and (Coarse sized (60% PB+40 %PM) + PS)

3.2.5. Water

Generally, water that is suitable for drinking is satisfactory for use in concrete. Water from lakes and streams that contain marine life also usually is suitable. When water is obtained from sources mentioned above, no sampling is necessary. When it is suspected that water may contain sewage, mine water, or wastes from industrial plants or canneries, it should not be used in concrete unless tests indicate that it is satisfactory. Water from such sources should be avoided since the quality of the water could change due to low water or by intermittent discharge of harmful wastes into the stream. In the present experimental programme, potable tap water is used for casting.

3.3. MIXTURE PROPORTIONING

The tests are carried out on a wide range of water-cement ratios, ranging from 0.4 to 0.52. The control mix is designed with the Indian Standard Code guidelines. For making the mixes containing plastics, the amount of plastics is calculated by using the specific gravity of plastics, in place of the specific gravity of coarse aggregates. The resultant mix proportions of all the mixes are tabulated in [Table 3.12](#).

Table 3.12 Mix proportions for per meter cube of various water cement ratios

S.No	W/C Ratio	Water Kg/m ³	Cement Kg/m ³	Fine Aggregates Kg/m ³	Coarse Aggregates Kg/m ³	Plastics Kg/m ³	Mix Proportions
MC1	0.40	194.4	485.9	503.8	1121.4	-	1:1.04:2.31
MC2	0.42	194.4	462.8	517.8	1127.9	-	1:1.12:2.44
MC3	0.44	194.4	441.8	528.3	1134.3	-	1:1.20:2.57
MC4	0.46	194.4	422.5	542.6	1138.7	-	1:1.28:2.69
MC5	0.48	194.4	404.9	552.8	1143.2	-	1:1.37:2.82
MC6	0.50	194.4	388.7	566.1	1143.9	-	1:1.46:2.94
MC7	0.52	194.4	373.8	575.4	1144.3	-	1:1.54:2.99
MP1	0.40	194.4	485.9	503.8	-	474.3	1:1.04:0.98
MP2	0.42	194.4	462.8	517.8	-	476.7	1:1.12:1.03
MP3	0.44	194.4	441.8	528.3	-	479.5	1:1.20:1.08
MP4	0.46	194.4	422.5	542.6	-	481.8	1:1.28:1.14
MP5	0.48	194.4	404.9	552.8	-	483.4	1:1.37:1.19
MP6	0.50	194.4	388.7	566.1	-	484.2	1:1.46:1.25
MP7	0.52	194.37	373.8	575.39	-	484.7	1:1.54:1.29

3.4 CASTING AND CURING

For casting, all the moulds were cleaned and oiled properly. These were securely tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage out of slurry. Careful procedure was adopted in the batching, mixing and casting operations. The coarse aggregates and fine aggregates were weighed first with an accuracy of 0.5 grams. The concrete mixture was prepared by hand mixing on a watertight platform. On the watertight platform, the coarse and fine aggregates were mixed thoroughly. To this mixture, the cement was added. These were mixed to uniform colour. Then water was added carefully so that no water was lost during mixing. Clean and oiled moulds for each category were then placed on the vibrating table respectively and filled in three layers. Vibrations were stopped as soon as the cement slurry appeared on the top surface of the mould.

The specimens were allowed to remain in the steel mould for the first 24 hours at ambient condition. After that these were demoulded with care so that no edges were broken and were placed in the curing tank at the ambient temperature for curing. The ambient temperature $27^{\circ} \pm 2^{\circ}$ C was the room temperature during casting.

After de-moulding the specimen by loosening the screws of the steel moulds, the cubes and cylinders were allowed to dry for one day before placing them in the temperature controlled curing tank for a period of 28 days.

3.5. TESTS CONDUCTED

3.5.1. Workability

The workability of concrete is assessed by compaction factor test. [Fig 3.3](#) shows the compaction factor test apparatus. And below [Table 3.13](#) and [Table 3.14](#) shows the compaction factor test results of controlled mix and plastic added concrete.

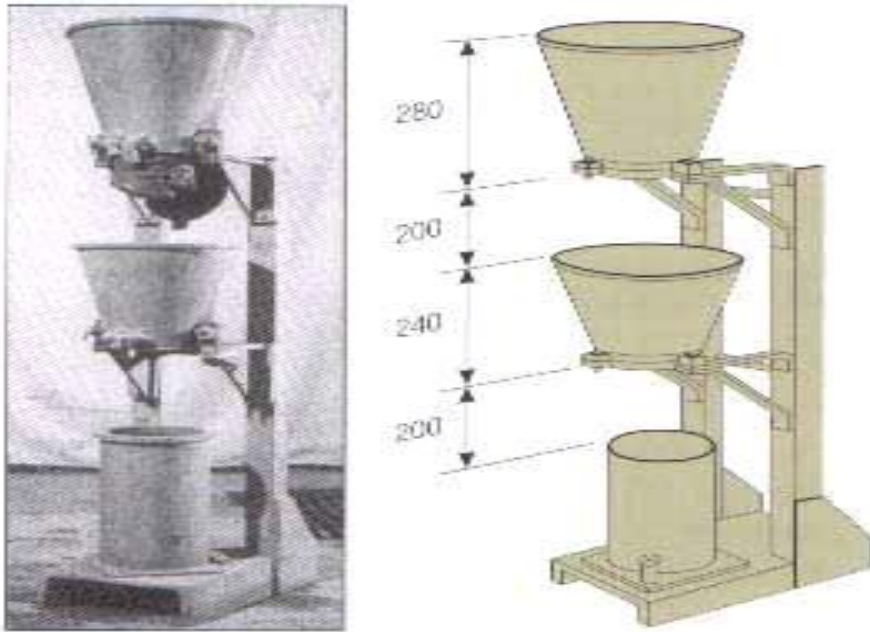


Fig. 3.3. Apparatus used for compaction factor test

Table 3.13: Compaction factor for the controlled mix

S.No.	W/C ratio	Compaction factor
1.	0.40	0.877
2.	0.42	0.880
3.	0.44	0.892
4.	0.46	0.893
5.	0.48	0.891
6.	0.50	0.893
7.	0.52	0.898

Table 3.14: Compaction factor for the mix with plastics

S.No.	W/C ratio	Compaction factor
1.	0.40	0.814
2.	0.42	0.852
3.	0.44	0.861
4.	0.46	0.873
5.	0.48	0.887
6.	0.50	0.891
7.	0.52	0.893

3.5.2. Compressive strength test

Cubical specimens of size 150 mm were cast for conducting compressive strength test for each mix. The compressive strength test was carried out as per IS: 516-1979. This test was carried at the end of 28 days of curing. The compressive strength of any mix was taken as the average of strength of three cubes.

3.5.3. Split tensile strength test

The tensile strength of the resultant mix is judged in terms of split tensile strength. For this, cylindrical specimens of size 150 mm dia × 300 mm height were cast. The test was conducted at the end of 28 days of curing and the average of three samples was taken as the representative split tensile strength of the mix.

3.5.4. Thermal analysis

The basic purpose of this test was to find out the effect of use of plastics on thermal conductivity of concrete. For doing this, copper-Constantine thermocouple was fabricated. The typical copper-Constantine thermocouple is shown in Fig. 3.4. In this study, this thermocouple was made by welding the wires of copper and Constantine. These wires were connected end to end by welding the wires point to point to make them circles by gas welding. The welded ends are taken as two junction points J_1 and J_2 . Junction J_1 was then kept in the centre of the cubical mould and the mould was filled with the control mix or with the mix containing plastics. The specimens were cast and cured for the required duration. The final specimen is as shown in [Plate.3.3](#). After the required curing period, the specimens are taken out of the curing tank and copper wire is cut from the centre. These new end of the copper wires are connected to the two (+) and (-) terminals voltmeter junction points of the digital voltmeter. The junction J_2 which is outside the cube is put into the ice bath. This ice bath is taken as reference junction here temperature is taken as reference 0°C . [Fig. 3.4](#) shows the digital circuit diagram of the

thermocouple of copper and the constantan with first junction into the sample and ice 0°C temperature reference as second junction. The emf of the voltmeter can then be correlated to the temperature at Junction J_1 of the thermocouple.

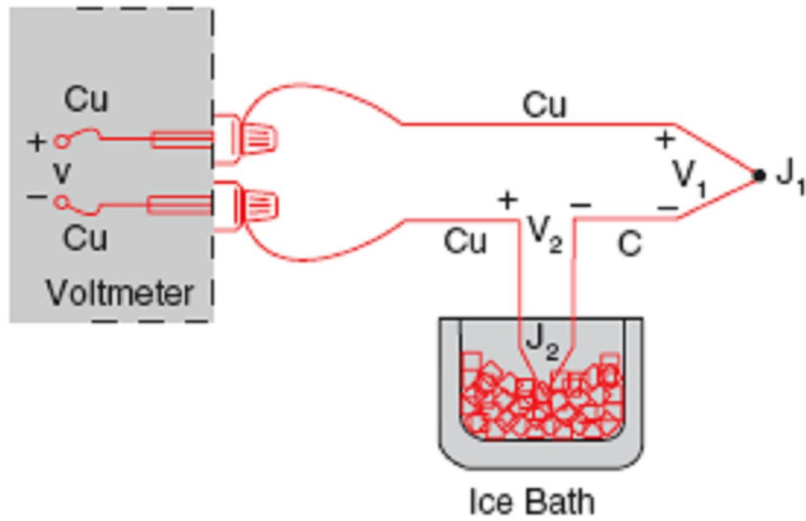


Fig. 3.4. External reference junction (Thermocouple connections)



Plate. 3.3. Copper and constantan wires putted into cubes

In the present work, it is required to know about the different in outside and inside temperatures in the cube when the coarse aggregates used are plastics and further compare it with the corresponding values of control mixes. For this, the concrete specimen was kept in the oven set at a constant temperature of 60⁰C. The wires are taken out of the oven and connected as described above to form thermocouple. The resultant arrangement is shown in [Plate. 3.4](#).



Plate. 3.4. Thermocouple arrangement of concrete cube in oven

The voltage of the system is monitored for a period 7 hours to find the temperature that is reached at the centre of cube, and also to obtain the time at which constant temperature is reached. The testy was terminated when the emf of the system reached a constant value.

CHAPTER 4

RESULTS AND CONCLUSIONS

4.1. GENERAL

In this chapter the parameters studied on the control concrete and plastic replaced concrete are discussed. The parameters such as unit weight, compressive strength, splitting tensile strength and thermal conductivity are discussed and comparison between the control concrete and plastic added concrete is represented.

4.2. DRY DENSITY

The dry density is measured for the cubes taken from the curing tank, just prior to compressive strength test. The value of dry densities obtained for the control mixes and for plastic concrete is shown in Fig.4.1 for all water-cement ratios. It is found from the testing that the unit weight of there is considerable decrease in unit weight when compared with the control concrete without plastic replacement. Water cement ratio does not affect the unit weight that much but the quantity of plastic as aggregates can reduce the unit weight of concrete considerably. It is found that the plastics replaced with concrete reduces the unit weight of concrete and can be used as light weight concrete. For the accuracy of the results the minimum three samples of the control concrete and three samples of plastic replaced concrete were casted and tested and average of three are taken for the accuracy of results. The results of unit weight of control and plastic replaced concrete are shown in Table 4.1. In order to compare the effect of plastics with normal aggregates, the percentage reduction in the unit weight of concrete achieved by using plastics as aggregates is found and is presented in Table 4.1. It can be seen from the Table that with the use of plastics, the dry density is reduced for all mixes, at all water-cement ratios. The density is reduced by nearly 35% for all the mixes. This reduction in dry density is due to the lower density of plastics as compared to the density of coarse

aggregates. The similar observation was made by (*Ismail and Al-Hasmi ,2007*) in their research work.

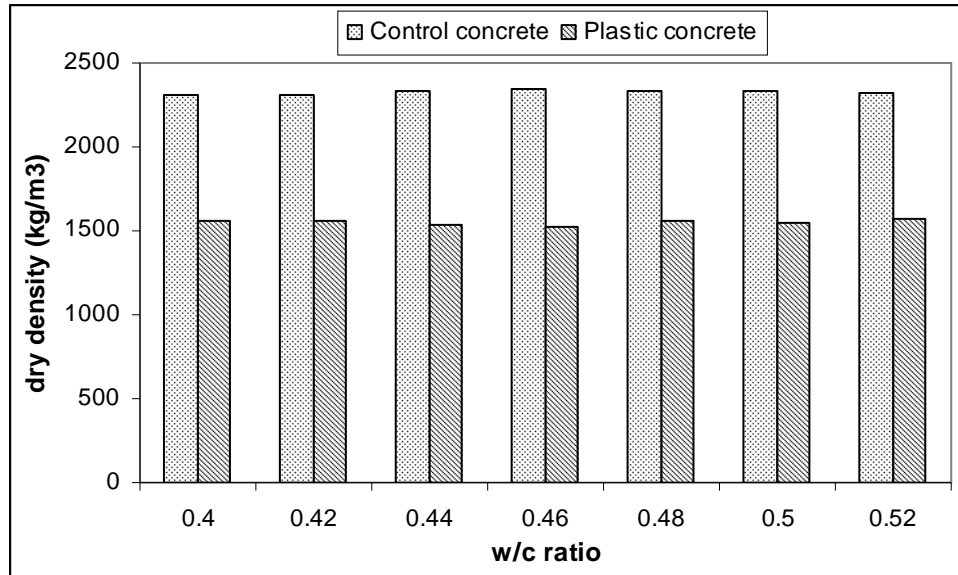


Fig. 4.1. Graph between w/c ratio and dry density of control concrete and plastic replaced concrete

Table 4.1 Dry densities of control concrete and plastic added concrete

w/c Ratio	Unit weight of (Kg/m ³)		Percentage reduction in unit weight (%)
	control concrete	plastic concrete	
0.4	2315	1555	32.8
0.42	2312	1558	32.6
0.44	2337	1533	34.4
0.46	2345	1524	35.0
0.48	2338	1559	33.3
0.5	2328	1545	33.6
0.52	2322	1572	32.3

4.3. COMPRESSIVE STRENGTH

The compressive strength for different water cement ratios of plastic added concrete and control concrete were tested at the end of 28 days using compressive strength testing machine as shown in Plate 4.1. The water cement ratios were taken as 0.4, 0.42, 0.44, 0.46, 0.48, 0.50, and 0.52. Three cubes of each water cement ratio are casted and the average of three test results is taken for the accuracy of the results. The concrete cubes were cured at room temperature. The values of compressive strength obtained are tabulated in Table 4.2 and Fig. 4.2. It is clear from the Fig that with the addition of plastics, the compressive strength of concrete reduces. The average reduction in compressive strength is 70%. This reduction in compressive strength is attributed to the decrease in adhesive strength between the plastic aggregates and the cement paste. It is consistent with the observation made by other researchers (*Choi et al 2005, Marzouk et al 2007*).

Also, it can be seen from the figures that for control concrete, the compressive strength increase with the decrease in water-cement ratio. It is an obvious fact as per Abrams water-cement ratio law, which states that the compressive strength of concrete is inversely proportional to the water-cement ratio of the mix. However, the compressive strength of concrete made with plastic is more or less constant. It can be due to the fact that due to reduction in bond strength between plastics and cement paste, the specimens fails due to failure of bond and water-cement ratio does not play an important role in enhancing strength of plastic concrete. Plates 4.2 and 4.3 respectively shows the typical failure patterns of control concrete and plastic concrete.



Plate 4.1. Compression testing machine (ACTM)

Table 4.2 Compressive strength of control and plastic added concrete

w/c Ratio	Compressive strength (MPa)		Percentage reduction in compressive strength (%)
	control concrete	plastic concrete	
0.40	39.67	13.09	67.00
0.42	38.63	11.39	70.51
0.44	38.47	10.65	74.24
0.46	37.74	10.21	72.94
0.48	35.37	9.96	71.84
0.50	32.11	9.44	70.60
0.52	27.67	10.06	63.64

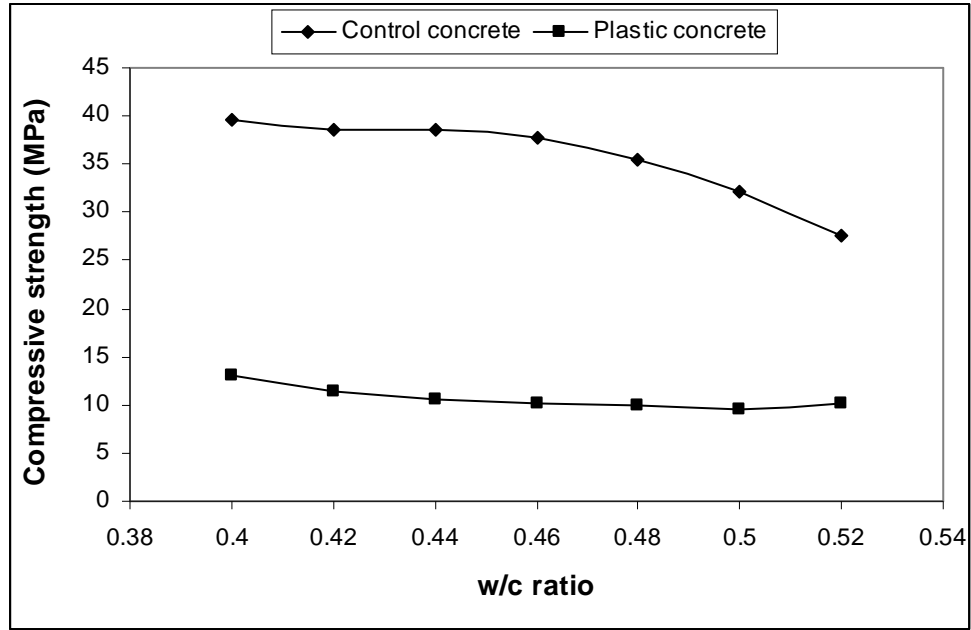


Fig. 4.2. Graph between water-cement ratio and Compressive strength of control and plastic replaced concrete



Plate. 4.2 Control concrete cube failure



Plate. 4.3 Plastic concrete cube failure

4.4. SPLIT TENSILE STRENGTH

The split tensile strength for different water cement ratios of plastic added concrete and control concrete is obtained tested at the end of 28 days. The water cement ratios were taken as 0.4, 0.42, 0.44, 0.46, 0.48, 0.50, and 0.52. The values are represented in Table 4.3 and Fig. 4.3. It is found that split tensile strength of plastics aggregates replaced concrete is less than the control concrete at all the water-cement ratios. This observation is similar to the one made in compressive strength test. The average reduction in split tensile strength of plastic concrete is 78%.

Table 4.3 Split tensile strength of control concrete and plastic concrete

w/c Ratio	Tensile strength (MPa)		Percentage reduction in tensile strength (%)
	Control concrete	Plastic concrete	
0.40	3.98	1.13	71.6
0.42	3.95	1.08	72.7
0.44	3.92	0.8	79.6
0.46	3.77	0.79	79.1
0.48	3.67	0.76	79.3
0.50	3.28	0.75	77.1
0.52	3.04	0.74	75.7

4.4.1. Failure modes of cylinders in splitting tensile test

Plate 4.4 shows the test set up of cylinders for doing the split tensile test. The failure patterns of control concrete and plastic concrete are shown in Plates 4.5 and 4.6 respectively. From the failure pattern, it can be seen that in the case of plastic concrete, the crack does not occur in the plastic, but goes around the plastic aggregate. This fact also indicates the poor bond strength between the cement paste and the plastic aggregates. In the case of control concrete, the failure took place right through the aggregates, indicating higher bond strength between the cement paste and the coarse aggregates. Due to this poor bond strength of plastic concrete, the compressive strength of concrete did

not show a gain with the decrease in water-cement ratio, as has already been discussed in Section 4.3.

It was also noticed that the control concrete specimens had the brittle type failure, that is, sudden breakage accompanied by sound. But for the specimens that had plastic aggregates in place of normal aggregates, the failure occurred smoothly failure without any noise during breakage. It also indicates that the addition of plastic aggregates will induce ductility into the concrete system. Therefore, when added in proper proportion, the concrete can be made ductile with the addition of plastics in concrete.

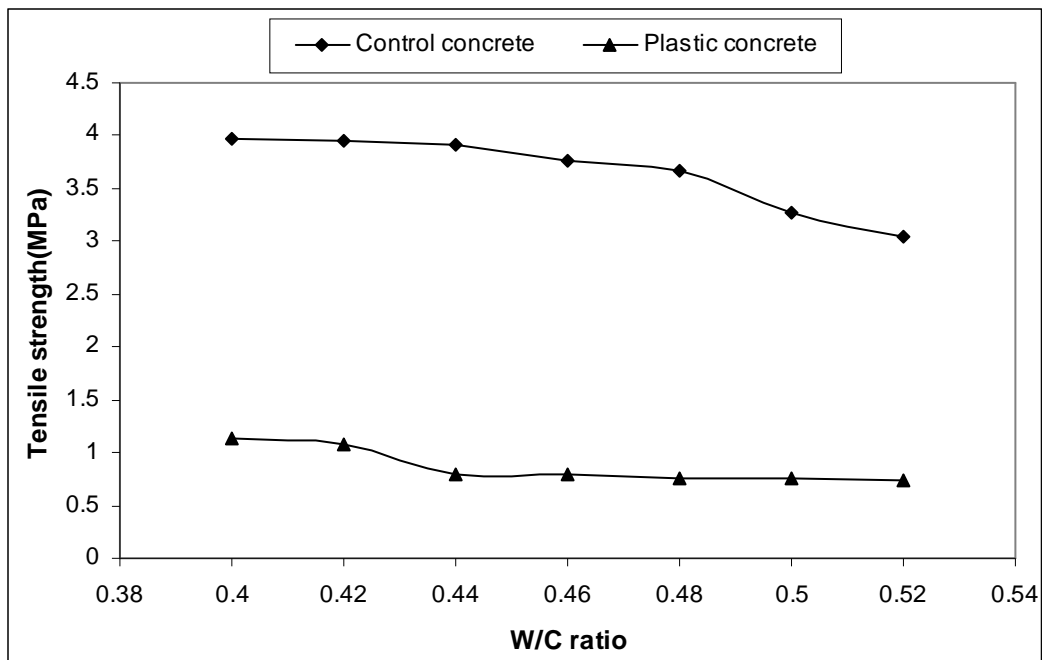


Fig. 4.3. Graph between W/C ratio and Tensile strength of control and plastic replaced concrete



Plate. 4.4. Test set up for conducting split tensile test on cylinders



Plate. 4.5. Failure pattern of control concrete



Plate. 4.6. Failure pattern of plastic concrete

4.4.2. Relationship between compressive strength and tensile strength

In order to obtain a relationship between the compressive strength and tensile strength of control concrete and plastic concrete, the graphs are obtained, as shown in Figs. 4.4 and 4.5 respectively.

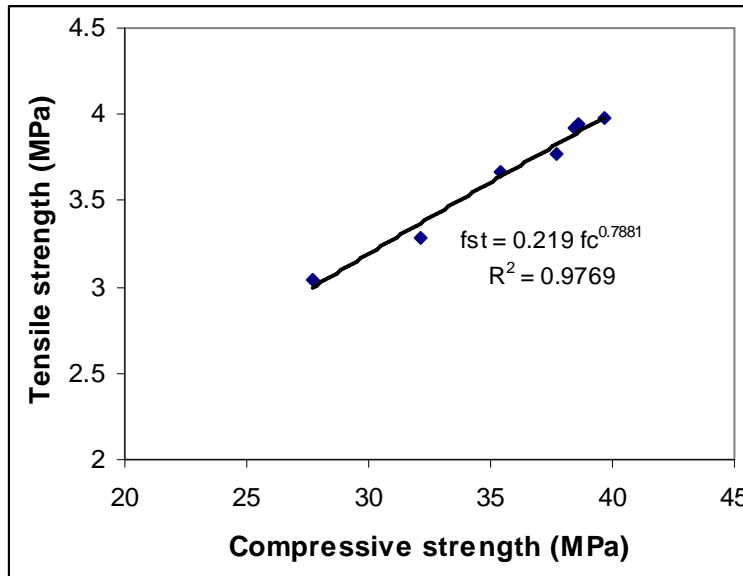


Fig. 4.4. Relationship between compressive strength and split tensile strength for control concrete

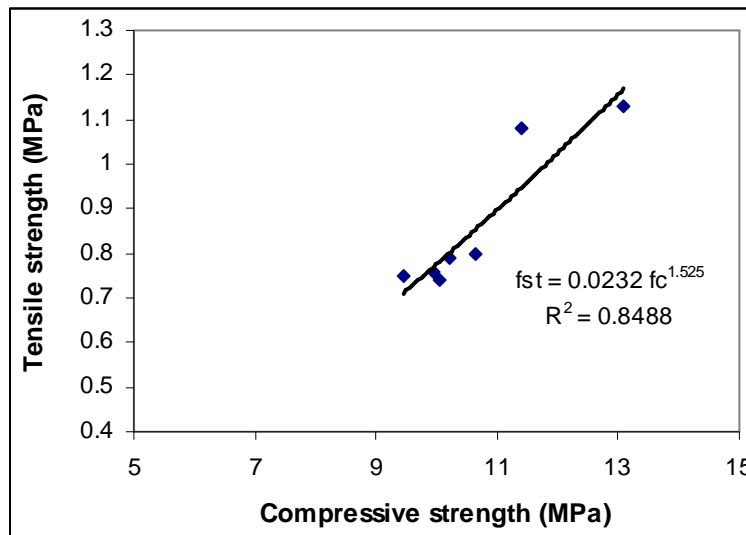


Fig. 4.5. Relationship between compressive strength and split tensile strength for plastic concrete

As can be seen from the figures, the power series can be used to depict the tensile strength of concrete from its compressive strength. However, the power is not same for control concrete and plastic concrete. The control concrete follows nearly the two-third power law, however, the power for plastic concrete is nearly 1.5. It indicates that the split tensile strength increases swiftly with the increase in compressive strength, as compared to the increase shown by control concrete.

4.5. THERMAL ANALYSIS OF CONCRETE

The thermal analysis was carried out on both the control concrete and concrete made by replacing 100% coarse aggregate with plastic aggregates. The water cement ratio was taken as 0.4, 0.42, 0.44, 0.46, 0.48, 0.50, and 0.52. The thermocouples were made with the copper and constantan wires connected with the ends by welding or shouldering. The test set up is explained in Chapter 3. The emf of the centre of the cube is obtained by using copper-Constantine thermocouple. The emf is then converted into temperature by using the following expression:

Temperature Conversion Equation:

$$T = a_0 + a_1 x + a_2 x^2 + \dots + a_n x^n \quad \dots (4.1)$$

This equation can be expanded to have the polynomial equation of the form:

Nested Polynomial Form:

$$T = a_0 + x(a_1 + x(a_2 + x(a_3 + x(a_4 + a_5 x)))) \text{ (5th order)} \quad \dots (4.2)$$

where x is in Volts, T is in °C

The value of constants for Copper-Constantine thermocouple is stated as under:

$$a_0 = 0.100860910$$

$$a_1 = 25727.94369$$

$$a_2 = - 767345.8295$$

$$a_3 = 78025595.81$$

$$a_4 = -9247486589$$

$$a_5 = 6.97688E + 11$$

$$a_6 = -2.66192E + 13$$

$$a_7 = 3.94078E + 14$$

Therefore, the equation for Copper-Constantine thermocouple can also be written as:

$$T = 0.100860910 + x (25727.94369 + x (- 767345.8295 \quad (7\text{th order}) \quad \dots (4.3) \\ + x (78025595.81 + x (-9247486589 + x (6.97688E \\ + 11 + x (-2.66192E + 13 + 3.94078E + 14 x))))))$$

The values of emf and the corresponding temperatures for the control concrete at all water-cement ratios is shown in Table 4.4. The values obtained for the plastic concrete is shown in Table 4.5. Also, the time required to reach a constant emf, and thus constant temperature, is mentioned in the Table.

Table 4.4: Internal temperature of concrete cube when normal aggregates are used

w/c Ratio	emf of Junction J1	Temperature of Junction J1	Time required to reach constant emf (hours)
0.40	0.0010	25.13	3 hours
0.42	0.0010	25.13	3 hours, 20 min.
0.44	0.0010	25.13	3 hours, 50 min
0.46	0.0011	27.26	3 hours, 40 min.
0.48	0.0012	29.29	4 hours, 10 min
0.50	0.0012	29.29	4 hours, 10 min.
0.52	0.0012	29.29	4 hours, 30 min

Table 4.5: Internal temperature of concrete cube when plastic aggregates are used

w/c Ratio	emf of Junction J1	Temperature of Junction J1	Time required to reach constant emf (hours)
0.40	0.005	12.78	6 hours, 30 min.
0.42	0.006	15.28	6 hours, 10 min.
0.44	0.006	15.28	6 hours, 50 min
0.46	0.007	17.76	6 hours, 30 min.
0.48	0.006	15.28	6 hours, 10 min
0.50	0.007	17.76	6 hours, 10 min.
0.52	0.007	17.76	6 hours, 30 min

From the Tables, it is seen that with the introduction of plastic aggregates in concrete, the temperature of the interior of concrete is lower than the control concrete. It indicates that the thermal conductivity of plastic concrete is lower than the control concrete. Not only the ultimate temperature reached is lower, the plastic concrete requires more time to reach a standard temperature. This leads to an important conclusion that the wall made by using plastic aggregates can help in keeping the room cooler than the outdoor temperature. The similar type of observation was made by *Elzafraney et al (2005)* while studying the ways by which the interior of the building can be kept warmer in cold climate.

CHAPTER 5

CONCLUSION AND SCOPE OF FURTHER STUDY

5.1. GENERAL

In the present work, recycled plastics were used as coarse aggregates and the properties of resultant mix were studied and compared with the control mix having normal aggregates. The conclusions drawn from the present study and the scope for further research are discussed in this chapter.

5.2. CONCLUSIONS

Following are the conclusions that can be made based upon the studies made by various researchers:-

1. Plastics can be used to replace some of the aggregates in a concrete mixture. This contributes to reducing the unit weight of the concrete. This is useful in applications requiring nonbearing lightweight concrete, such as concrete panels used in facades.
2. For a given w/c, the use of plastics in the mix lowers the density, compressive strength and tensile strength of concrete.
3. The effect of water-cement ratio on strength development is not prominent in the case of plastic concrete. It is because of the fact that the plastic aggregates reduce the bond strength of concrete. Therefore, the failure of concrete occurs due to failure of bond between the cement paste and plastic aggregates.

4. Introduction of plastics in concrete tends to make concrete ductile, hence increasing the ability of concrete to significantly deform before failure. This characteristic makes the concrete useful in situations where it will be subjected to harsh weather such as expansion and contraction, or freeze and thaw.

5. The inclusion of recycled aggregates in the concrete of the buildings under investigation has been shown to be advantageous from an energy point of view. The use of [plastic aggregates helped in keeping the interior cooler, when the outside temperature is raised, as compared to the corresponding control concrete.

5.3. SCOPE FOR FURTHER RESEARCH

The use of recycled plastics in concrete is relatively a new development in the world of concrete technology and lot of research must go in before this material is actively used in concrete construction. The use of plastics in concrete lowered the strength of resultant concrete, therefore, the research must be oriented towards ternary systems that helps in overcoming this drawback of use of plastics in concrete.

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