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Structural applicability of plastic incorporated concrete

Aplicabilidad estructural del hormigón con plástico incorporado

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ABSTRACT

Modulus of elasticity of concrete indicates the resistance of the material to deflection. The elastic modulus depends on the components of the concrete. When new replacement materials are introduced into the concrete, it is important to evaluate the modulus of elasticity of that concrete as it is used in structural applications. Nowadays plastic waste is used in pavement construction. Incorporation of plastic bottle waste in concrete as a replacement for aggregates is gaining attention. The application of this concrete in structures need to be studied. Evaluation of elastic modulus of plastic aggregate concrete is a first step towards its structural applicability. As an initial step to this study, two grades of normal concrete are prepared and its elastic modulus is evaluated. The result shows similar relation of compressive strength and elastic modulus as per standard code value.

Keywords— Elastic modulus, concrete, plastic aggregate concrete, plastic bottle waste.

RESUMEN

El módulo de elasticidad del hormigón indica la resistencia del material a la deflexión. El módulo de elasticidad depende de los componentes del hormigón. Cuando se introducen nuevos materiales de reemplazo en el hormigón, es importante evaluar el módulo de elasticidad de ese hormigón a medida que se utiliza en aplicaciones estructurales. Hoy en día, los residuos plásticos se utilizan en la construcción de pavimentos. La incorporación de desechos de botellas de plástico en el concreto como reemplazo de los agregados está ganando atención. Es necesario estudiar la aplicación de este hormigón en estructuras. La evaluación del módulo de elasticidad del hormigón con agregado plástico es un primer paso hacia su aplicabilidad estructural. Como paso inicial de este estudio, se preparan dos grados de hormigón normal y se evalúa su módulo de elasticidad. El resultado muestra una relación similar de resistencia a la compresión y módulo elástico según el valor del código estándar.

Palabras clave: módulo de elasticidad, hormigón, hormigón con agregado plástico, residuos de botellas de plástico.

INTRODUCTION

The elastic modulus is a quantity that measures an object or substance's resistance to being deformed elastically when a stress is applied to it. Modulus of elasticity of a material is defined by the ratio of the applied stress to the corresponding strain within the elastic limit. The value of elastic modulus of the concrete is calculated using some empirical formulae provided by different codes. These equations are based on the relationship between modulus of elasticity of concrete and its compressive strength. The applicability of these empirical formulae for different types of concrete developed by replacing and/or addition of various constituents are not clear. So, it is important to evaluate the elastic modulus of such types of concrete. With the drastic increase in the population, the use of plastics has increased which created problems in its disposal. Incorporating plastic wastes in concrete can be one way of reducing the disposal problem of plastic wastes and the excessive extraction of natural aggregates. Concrete with plastic aggregates can be cheaper compared to conventional concrete. Even though the suitability of plastic wastes as aggregates in the concrete are studied, its structural applications are not seriously noticed. Polyethylene Terephthalate (PET) bottle waste is used as partial replacement for coarse aggregate in this study and the elastic modulus of concrete containing plastic aggregates is evaluated.

For studying about the effect of waste polyethylene terephthalate as an aggregate in concrete. PET bottle waste was made into 3 types and used as coarse flakes (PC), fine fraction (PF), plastic pellets (PP). In this study, 0,5,10,15 percentage replacement was done for each type of PET aggregate. Development of compressive strength of PET aggregate concrete was similar to that of conventional concrete. Plastic pellets showed less reduction in 28day compressive strength and it was 16% and 7day compressive strength was almost equal for all the mixes. Tensile/compressive strength ratio gives idea about toughness of concrete and it was 49.38% higher for 15% coarse flakes aggregate concrete than normal mix. 43.63% increase was observed for flexural/compressive strength ratio for 15% coarse flakes. Concrete specimens with PET-aggregate are able to withstand additional loading after they crack [NabajyotiSaikiaa*et al.*, (2013)].

In an experimental study on use of waste plastic as coarse aggregate in concrete with admixture superplasticizer polycarboxylate ether, 0, 5,10,15,20 percentages of coarse aggregate were replaced with plastic waste. Slump value showed 62.5% increase on 20% replacement with plastic waste in the experiments. 6.3% increase in 7day compressive strength and 4.05% increase in 28day compressive strength was observed on 15% replacement with plastic aggregates. 14.67% and 9.75% increase observed on 10% replacement in tensile and flexural strength respectively. The use of plastic aggregate made concrete more ductile than the conventional concrete [Rafiq Ahmed Pirzada *et al.*, (2018)].

In an experimental study on plastic waste as coarse aggregate for structural concrete 0, 5, 10, 15% replacement of coarse aggregate with plastic waste was done and 32.55% increase in 7day and 6% increase in 28day compressive strength was observed for 10% replacement with plastic aggregates. 20.9% increase in split tensile strength and 48.8% increase in flexural strength was observed for 10% replacement. 20% of plastic waste aggregate can be incorporated as coarse aggregate replacement in concrete without any long-term detrimental effects and with acceptable strength development properties [Subramani T, *et al.*, (2015)].

For prediction of the modulus of elasticity of high strength concrete, 45 mix proportions including 0, 5,10, 15, 20% of silica fume, 0.24, 0.3, 0.4 w/c ratios and limestone, quartzite, andesite types of coarse aggregates were analyzed. Relation between elastic modulus of coarse aggregate and that of concrete is evaluated. Mechanical properties of high strength concrete depend on w/c ratio, silica fume ratio, types of aggregates. Equations from different codes were used and its credibility was checked with new mixes and a new relation was developed. Equations were proposed based on compressive strength [Mostofinejad D *et al.*, (2005)].

$$E_C = 10.25fc^{0.316} \quad \text{(limestone)} \qquad (1)$$

$$E_C = 8fc^{0.352} \quad \text{(Andesite)} \qquad (2)$$

$$E_C = 10.75fc^{0.312} \quad \text{(Quartzite)} \qquad (3)$$

In a study on establishing a relationship between modulus of elasticity and compressive strength of recycled aggregate concrete Test results from 121 publications over a period of 43 years were collected and a statistical analysis is done with the purpose of understanding the loss of modulus of elasticity based on quality and replacement level of recycled aggregates. Up to 30% replacement of recycled aggregates has minimal effects on elastic modulus. Use of recycled aggregates as coarse aggregate and fine aggregates showed 15% and 40% reduction in elastic modulus. Elastic modulus is influenced by cement paste, aggregate nature and age of concrete. Equations from different studies were compared [Brito de Jorge *et al.*, (2016)].

$$E_C = 12.96\left(\frac{fc}{10}\right)^{0.3} \quad \text{(50\% replacement)} \qquad (4)$$

$$E_C = 18.26\left(\frac{fc}{10}\right)^{0.3} \quad \text{(100\% replacement)} \qquad (5)$$

Ultra- high-performance concretes are highly durable and have high compressive and tensile strength. Data were collected from literatures and also tested to evaluate its accuracy and the accuracy depends on the size of collected data. When compressive strength increased elastic modulus also increased but not at the same rate as normal concrete. Compressive strength varied from 124-162MPa and elastic modulus from 37-46 GPa. New equation was proposed to predict elastic modulus with reasonable prediction accuracy [Alsalman Ali *et al.*, (2017)]

$$E_C = 8010 fc^{0.36} \text{ , } E_C \text{ in MPa} \qquad (6)$$

MATERIALS AND METHODS

The methodology adopted for this study is as follows:

1. Selection of area of study: The research problem was identified.
2. Literature Review: The information required for the selected topic was collected from literature survey.
3. Collection of Materials: The materials such as cement, coarse aggregate, fine aggregate, PET bottle wastes, superplasticizers were collected.
4. Tests on Materials: The materials were tested for determining its properties required for designing the mix.
5. Mix Design: Mix design of M25 and M30 grades of concrete were prepared.
6. Casting of Cylinder Specimens: Cylinder specimens(150x300mm) are casted for control mix M25 and M30 grades of concrete.
7. Testing of Specimen: Compressive strength for 28 day and stress-strain readings using compressometer were done on cylinder specimens.
8. Data Analysis: Results from the tests wereanalyzed and a relation between elastic modulus and compressive strength of concrete was developed.
9. Interpretation of Results: Conclusion and discussions were derived from the analysis of test results.

The materials used in the experimental study are, cement (PPC), fine aggregate, coarse aggregate, PET bottle flakes as replacement material for coarse aggregate and superplasticizer. In the present experimental work, Portland Pozzolana cement was used confirming to IS 1489:1991 (Part 1). Cement is generally used as the main binder material. Fine aggregates usually consist of river sand. Due to the scarcity of river sand and the environmental impact of river excavations, M-sand was used as the fine aggregate in the present study. M-sand used was confirming to Zone I of IS 383:1970 (Reaffirmed 2016). The coarse aggregates are generally crushed stones with size ranging from 20 mm to 4.75 mm. They occupy around 70% of the total volume of concrete. The coarse aggregates used were with a nominal size of 20 mm downgraded crushed aggregates. The properties of coarse aggregates were confirming to IS 383:1970 (Reaffirmed 2016).Plastic used in this research is PET (polyethylene terephthalate) bottle flakes. The size ranges from 14mm to 18mm. The bottles were collected from the defective bottle waste in manufacturing companies.To improve the workability of concrete superplasticizer is used. The superplasticizer used in the present study is Conflo LN. It is a high molecular weight polymer based on lignosulphonate and is chloride-free. It conforms to BS 5075 Part 1 (1982), and IS 2645:1978. A dosage range of 0.15% to 0.5% by weight of cement is recommended. Water is an important ingredient of concrete, as it actively participates in the chemical reaction with cement. The strength of cement concrete comes from the bonding action of the hydrated cement gel. Table 1 gives the various tests and properties of the materials.

Table 1. Materials and Properties

Material	Experiment	Result
Cement	Specific Gravity	3.2
	Initial Setting Time	40 minutes
	Consistency	33%
Coarse Aggregate	Specific Gravity	2.65
	Water Absorption	0.72%
Fine Aggregate	Specific Gravity	2.63
	Water Absorption	1.23%
Plastic Flakes	Specific Gravity	1.29
	Water Absorption	0

The mix was designed as per IS 10262:2019. The coarse aggregate is replaced with plastic flakes by volume. The proportions of the components in the plastic aggregate concrete in each mix are given in Table 2.

Table 2. Mix Proportions

Mix	Nomenclature	Proportion
Concrete mix of Grade M25	CM25	1: 2.36: 3.57:0.005
Concrete mix of Grade M25 with coarse aggregate replaced by 5% plastic flakes	CM25P5	1: 2.36:3.39:0.087:0.005
Concrete mix of Grade M25 with coarse aggregate replaced by 10% plastic flakes	CM25P10	1: 2.36: 3.218: 0.174: 0.005
Concrete mix of Grade M25 with coarse aggregate replaced by 15% plastic flakes	CM25P15	1: 2.36: 3.039: 0.26: 0.005
Concrete mix of Grade M30	CM30	1: 2.08: 3.15: 0.004
Concrete mix of Grade M30 with coarse aggregate replaced by 5% plastic flakes	CM30P5	1: 2.08: 2.99: 0.076: 0.004
Concrete mix of Grade M30 with coarse aggregate replaced by 10% plastic flakes	CM30P10	1: 2.08: 2.83: 0.15: 0.004
Concrete mix of Grade M30 with coarse aggregate replaced by 15% plastic flakes	CM30P15	1: 2.08: 2.68: 0.23: 0.004

Cylinder specimens of 300mm height and 150mm diameter were casted for M25 and M30 grades of concrete and tested for 28^{th} day compressive strength and the modulus of elasticity was evaluated. The deformations were obtained directly from longitudinal compressometer attached to the specimen. Figure 1 shows the casted specimens and the testing of cylinder specimen.

Fig 1 Casting and testing of cylinder specimen

RESULTS AND DISCUSSIONS

The deformation values are directly obtained from the longitudinal compressometer and strain is calculated from it. Compressive strength and stress are calculated from the compression testing machine load values. A graph is plotted between compressive strength and modulus of elasticity of concrete. Figure 2 and Figure 3 shows the graph plotted between compressive strengths and elastic modulus of M25 and M30 grade concrete respectively. The relation shows similar results as perIS 456:2000.

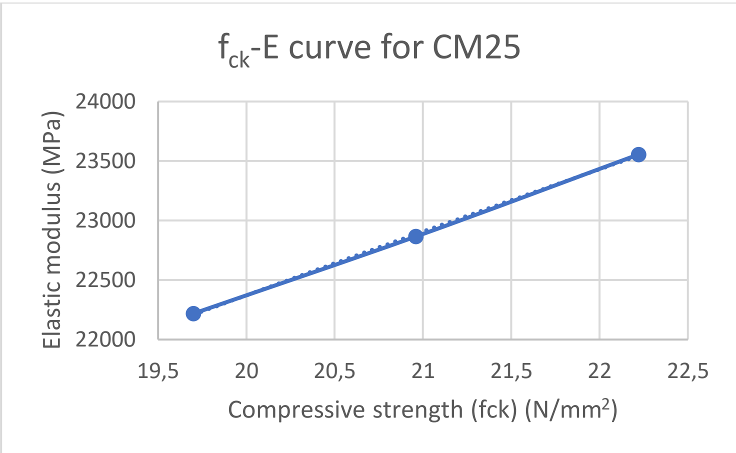

Fig 2 Relation between compressive strength and elastic modulus of M25 grade concrete

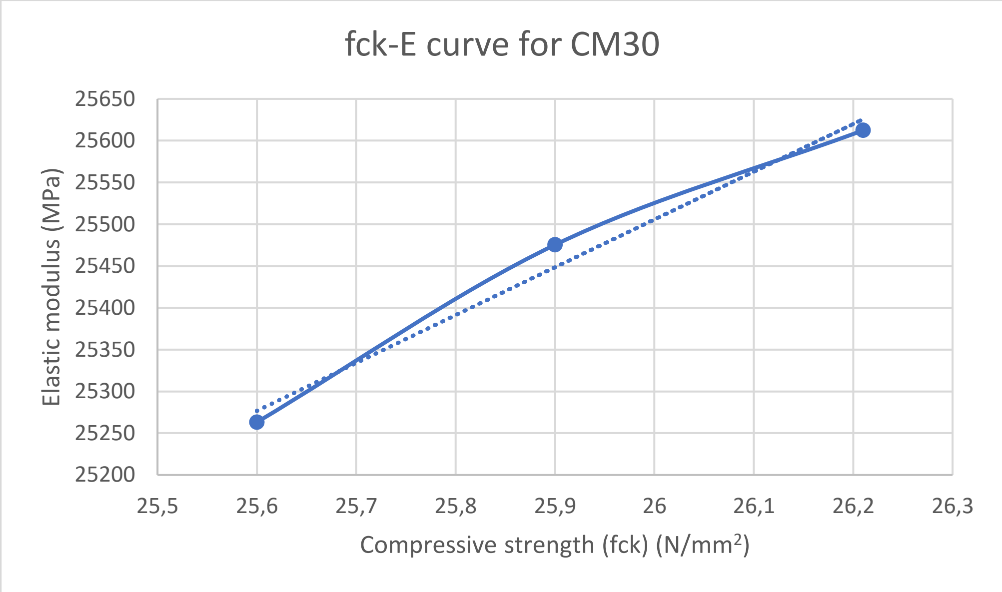

Fig 3 Relation between compressive strength and elastic modulus of M30 grade concrete

The elastic modulus plays a vital role in the structural behaviour of the materials in construction industry. Various replacements are studied in the concrete, but not widely used in the construction. That may be due to the uncertainty in the behaviour of those new materials in the structures. It is important to evaluate and study the structural behaviour of these materials along with the strength properties. One of the basic characteristics of the materials is its young's modulus or the elastic modulus. Plastic as a waste material, it has got durability and chemical resistance and therefore it can be utilized in the concrete as a replacement material. The structural applications can be studied by evaluating the modulus of elasticity of this plastic aggregate concrete. This makes concrete ecofriendly. The paper presents an initial work under the studies to be carried out for the evaluation of elastic modulus of plastic aggregate concrete.

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