INCORPORATION OF WASTE POLYETHYLENE TEREPHTHALATE INTO CONCRETE USING STATISTICAL MIXTURE DESIGN

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ABSTRACT

This paper investigated the incorporation of waste Polyethylene Terephthalate (PET) into concrete as a replacement for natural fine aggregate and found an optimal combination of components that produces a useful concrete product. Six components were considered: cement, water, coarse aggregate, fine aggregate, super plasticizer, and waste PET. A total of 31 mixes were prepared based on a statistical mixture design approach. The responses of these mixtures were workability, compressive strength, and splitting tensile strength.

The waste PET was first reduced in volume by shredding and then combined with the rest of the components. The responses from the experiments were statistically analyzed and a model fitted to each response. Linear models were found to fit the responses best. Using the desirability function approach, four optimal options were selected and then verified in the lab by comparing the experimental with the predicted values. Except for one, all the values fell within the 95% prediction interval. The option that best fulfilled the workability and strength requirements was found. The average response values obtained with this combination were:(1) compressive strength of 23.8 MPa; (2) slump123mm, and (3) splitting tensile strength of 3.33 MPa. This mix can be used in basements foundation walls or slabs, inside buildings not exposed to freezing temperatures. It is recommended that future work should consider method of mixing, time of mixing, volume of mix, curing conditions, and other responses to further understand the characteristics of incorporating waste PET into concrete.

Introduction

The plastic industry is one of the largest industries worldwide. Globally, in 2013, over 299 million tons of plastic were produced. Plastic has replaced paper, cardboard, metal and glass (Andrady, 2015). This displacement is a result of several advantages that plastic has over these other materials. Plastic is low-cost, lightweight and easy to handle, it also has relatively high strength and corrosion resistance (Andradi, 2015; Ferreira et al., 2012). Because plastic products have a large presence in a variety of markets (e.g. packaging, automotive, healthcare), these markets are directly contributing to increase the volumes of plastic in the waste stream (Silva, de Brito, and Saikia, 2013).

Plastic consumption has increased dramatically worldwide. This is in contrast to the recycling rate, which has remained low (Gu and Ozbakkaloglu, 2016). In USA, the contribution of plastic to the waste stream has increased from an average of 0.39 million tons in the 1960s to 31.75 million tons in 2012. Over the span of 50 years, the recycling rate has increased only 8.8%, which makes 2 plastic waste volume a serious issue for solid waste management (Gu and Ozbakkaloglu, 2016).

Every year in the Canadian province of Newfoundland and Labrador, approximately 4-thousand tons of plastic are consumed, which is approximately 8% of the solid waste generated in the province. This plastic waste is collected, compacted and sent to other provinces. Because of the option of sending plastic waste to other provinces, Newfoundland has not yet developed any long-term strategy for the management of this solid waste. This has drastic economic and environmental impacts (Government of Newfoundland, 2002).

Waste Polyethylene Terephthalate (PET) in the waste stream

Polyethylene Terephthalate (PET) is one of the main fractions of the plastic waste stream (Silva et al., 2013). PET is mostly employed as a multi-purpose plastic for bottled water, soft drinks, and as single-use packaging material (Andrady, 2015). Products made of PET are generally large in volume and can take approximately one thousand years to decompose under natural environmental conditions (Silva, et al., 2013; de Brito and Saikia, 2013). Once being collected, the most common treatment options for waste PET are: incineration, land filling, and recycling (Gu and Ozbakkaloglu, 2016). Incineration 3 takes advantage of the calorific properties of the polymers, which can then be used as fuel. However, there are concerns related to the generation of gases and fly ash that would result in air pollution (Andrady, 2015).

Land filling is considered as the least desirable treatment option. Because it requires of large amount of land and quantities of waste PET, and may lead to potential environmental issues due to leachate generation and gas emission (de Brito and Saikia, 2013). Recycling, on the other hand is currently considered as the best solution for addressing the problem of waste PET. (Gu and Ozbakkaloglu, 2016; Ge, Huang, Sun, and Gao, 2014). However, the recycling and reuse of waste PET have not being correctly performed. In 2012, in USA, 4.5 million tons of PET waste was available for recycling but only 880 thousand tons were recycled. This means that 80.1% of the available PET was discarded (Gu and Ozbakkaloglu, 2016).

METHODOLOGY

the methodology of statistical mixture design was applied for the mixing of the concrete incorporating waste PET. The components and their ranges were determined and set. The number of mixes was defined according to the mixture design approach. The experiments were setup and carried out in the concrete laboratory.

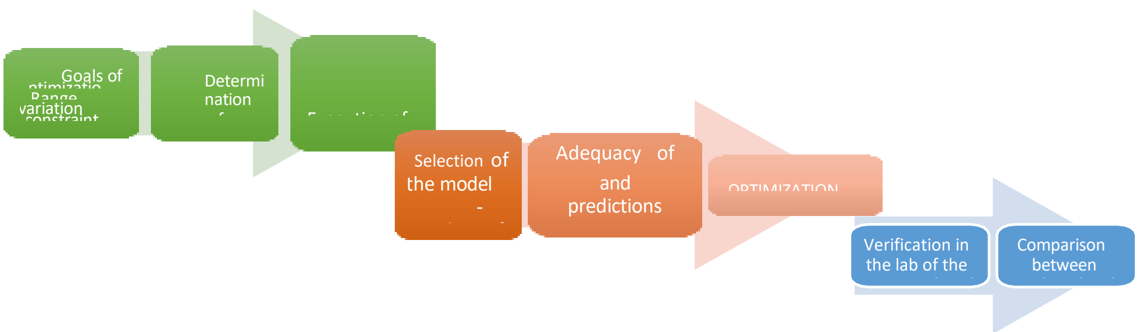


Figure 1: Mixture design process

determination of optimization goals, selection of the components and their ranges of variation and additional constraints; 2) identification of the responses and the number of experiments; and 3) execution of the experiments and measurement of the responses.

The second stage involves 1) selection of the model through the analysis of variance (ANOVA); 2) analysis of adequacy, through lack of fit test, R-squared adjusted and predicted, and graphical analysis of residuals; and 3) optimization through graphical and numerical optimization using the desirable function approach. In the third stage, the proposed optimal combination of components should be tested and confirmed (Myers and Montgomery, 2009). The actual and predicted values are compared. The experimentation is either completed or the design is augmented through the addition of few more experiments to obtain better results (Anderson and Whitcomb, 2005).

In this study, the constrained mixture design was employed, and the commercial available software Design Expert 10 (Statease Inc.) was used for the design, statistical analysis, definition of the points (experiments), and optimization of the mixture

Selection of materials

The materials selected were based on achieving the proposed criteria as well as the availability of materials in the university lab. The selected materials were Portland cement, tap water, coarse aggregate (crushed stone), fine aggregate (sand), and waste PET aggregate. Furthermore, super plasticizer was added to the mixture to address concerns about w/c ratio and workability. Batch size is selected as 0.03 m3 of concrete. Because of the small amount of concrete mixed in each batch, air volume was not considered as a component.

Cement

The cement selected was an ordinary Type 1 Portland cement. It is available at the university lab and meets the requirements of the ASTM C150/C150M-17.

Water

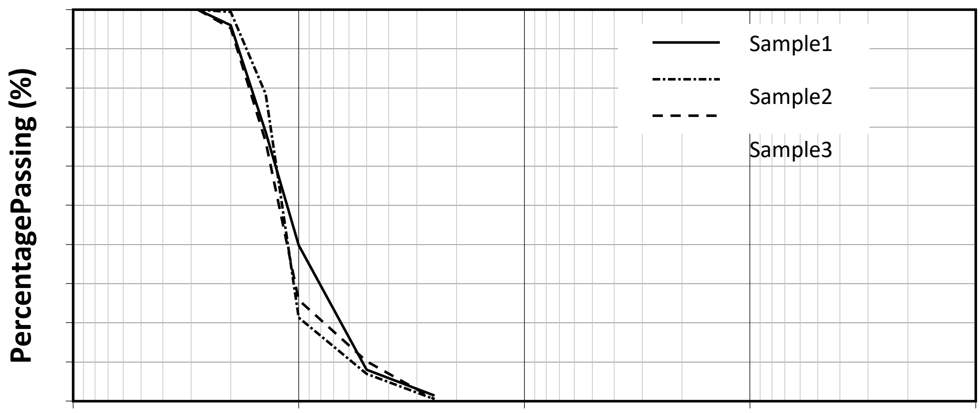
The water used for the experiments was tap water at room temperature from the university lab.

Aggregates

Fine and coarse natural aggregates were provided from local suppliers. The fine aggregate was sand (crushed granite). The coarse aggregate was crushed stone with a maximum size of 20 mm. Sieving of coarse aggregate was executed according to the standard ASTM C136M-14 as shown in Table and Figure . The sieving analysis of fine aggregate was also performed according to the standard ASTM C136 as shown in Table and Figure . The specific gravity of the coarse aggregate was tested according to the standard ASTM C127-15 and the specific density of the fine aggregate was measured according to the standard ASTM C 128-15. Table shows the results of specific gravity, bulk density, and absorption for coarse and fine aggregate.

Sieve size (mm)	%Passing by mass		
	Coarse 1	Coarse 2	Coarse 3
28	100	100	100
20	96	99.4	95.3
14	68.7	78.4	66.2
10	39.8	21.3	25.8
5	8	6.9	10.1
2.5	1.4	0.5	0.5

Table : Grading of the coarse aggregate used in the experiments



Conclusions

The statistical mixture design approach was shown to be a useful and practical tool for the examination of the influences among components in mixtures. For this study, 31 experiments were conducted to combine six different components and the responses of slump, compressive strength, and splitting tensile strength were statistically analyzed. Linear models fitted all the studied properties (measured responses). The adequacy of the model and the residuals were analysed. The adjusted R-squared and predicted R-squared for all the models were: (1) compressive strength: 0.73 and 0.65 (2) slump: 0.64 and 0.52 (3) splitting tensile strength: 0.79 and 0.73, respectively. These values suggested a high chance of appropriate prediction of new observations. Finally, through numerical optimization, the project goals were set and the optimized combinations of components were found. Four combinations were subsequently tested in the laboratory and compared to the predicted values.

REFERENCES

Aïtcin, P. C, & Mindess S. (2011). Sustainability of concrete. Modern Concrete Technology. Spon Press. Abingdon, Oxon.

Akçaözoğlu, S., Atiş, C., Akçaözoğlu, K. (2010). An investigation on the use of shredded waste PET bottles as aggregate in lightweight concrete. Waste Management, 30, 285-290.

Albano, C., Camacho, N., Hernández, M., Matheus, A., Gutiérrez, A. (2009). Influence of content and particle size of waste PET bottles on concrete behaviour at different w/c ratios. Waste Management, 29, 2707-2716.

Alexander, M. and Mindess S. (2005). Aggregates in concrete, Taylor and Francis, New York, NY, USA.

Anderson, M.J., & Whitcomb, P.J. (2005). RSM simplified: optimizing process using response surface methods for design of experiments. Productivity Press.

Andrady, A. (2015). Plastics and environmental sustainability. Wiley and sons. New Jersey, NY.

ASTM C494/C494M-17, (2017). Standard specification for chemical admixtures for concrete. Annual Book of ASTM standards, American Society for Testing and Materials, West Conshohocken, PA, USA.

ASTM C143/C143M-15, (2015). Standard test method for slump of hydraulic cement concrete. Annual Book of ASTM standards, American Society for Testing and Materials, West Conshohocken, PA, USA.

ASTM C39/C39M-18, (2018). Standard test method for compressive strength of cylindrical concrete specimens. Annual Book of ASTM standards, American Society for Testing and Materials, West Conshohocken, PA, USA.