PARTICLE SIZE EFFECT ON OPTIMAL MIXTURE RATIO OF TIN SLAG POLYMER CONCRETE UNDER COMPRESSION

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ABSTRACT

Tin slag waste is difficult to be disposed of openly due to its radioactive content. In order to overcome this current problem, researches are being carried out for future applications of tin slag as aggregate: either as filler or to replace aggregates in polymer concrete and cement-based concrete. In addition, sustainable development in the construction industry and the conservation of natural resources require using recycled and industrial co-products of all kinds in construction. Thus, this research aims to investigate the potential use of tin slag/polymer concrete for future engineering structure applications. The high silica content of tin slag is expected to offer enhancement in compressive strength for concrete in general. In this study, the mechanical properties such as compressive strength, modulus and deformation are investigated in relation to aggregate size and mixture ratio. The raw form of tin slag is sieved to segregate to four different sizes, then bound to unsaturated polyester resin with different mixture weight ratio. During sample preparation, the mixture is moulded in Poly Vinyl Chloride (PVC) tubes and left to be cured at room temperature for at least 24 hours. Under compression test, the test samples are loaded using Instron 600 kN universal testing machine at a loading rate of 1 mm/min in accordance to ASTM C 579-01. The test results are then correlated with compressive strength, modulus and deformation. From the analysis it shows that the mixture weight ratio of different polyester weight percentage influence the mechanical properties of the test samples. The optimum mixture weight ratio is 70 (tin slag):30 (polyester) under fine size aggregate (below 1 mm). It is also observed that the maximum compressive load varies between four mixture weight ratios confirming that 70 (tin slag):30 (polyester) under fine size aggregate (below 1 mm) produces higher impact on the strength, modulus and deformation properties of the test samples.

Keywords: Tin slag, mixture ratio, compressive properties.

INTRODUCTION

Polymer concrete (PC) employs the composite making principles to exploit the properties of heterogeneous materials. The presence of aggregates (hard phase) and binder (soft phase) completes the composite system by offering mechanical properties that cannot be achieved by utilizing either of the constituents. PC results from the polymerization of resin which surrounds or coats the aggregates to provide excellent adhesion and strength. The development of PC dates back to the second half of twentieth century when it was proposed as an alternative to concrete in certain applications such as building cladding.

PCs are valued for their functional properties. Their excellent strength, vibration absorption, freeze-thaw resistance and impermeability substantiate their usage as an alternative system in specific applications. These functional qualities help them get a niche in as wide range of applications as flooring material, paving materials, repairing agent and adhesives. Despite several advantages and performance features, PC systems lack high temperature resistance and adequate ductility.

The properties of PC are an interplay of processing parameters, aggregate types, resin characteristics and curing conditions. Also, the effect of aggregate size and resin concentration are of great importance. Normally, PC shows an optimum concentration of resin content to offer the best mechanical properties. The optimum values of resin vary based on the types of aggregates and the sizes.

One aspect of PC versatility issues from its amenable nature to accept different varieties of aggregates and resins. A large variety of aggregates such as basalt, slags, granite and foundry sand have been utilized by researchers for a variety of aims including sustainable practices and structural performances. One of these ends is to utilize process industry by-products for sustainable goals by finding avenues where these products can be re-used. This approach has stimulated research with an aim to assess and promote the use of slag products as structural grade aggregates. Various researches have been published in this domain seeking reduction in cost, optimum resin ratio and reducing voids etc.

Our local tin slag contained substantial amount of Thorium and Uranium which the level exceed permissible limit adopted by Malaysia and many importing nation. This is due to the alluvial tin mineral (cassiterite) mined in Malaysia is mixed with other heavy minerals such as ilmenite, zircon, monazite and also xenotime. Monazite and xenotime are radioactive minerals and contain considerable amount of uranium and thorium. Some of these minerals are present in the tin mineral as inclusions.

Currently, accumulation of tin slag waste is facing difficulty to openly dispose due to its radioactive content. The amount of radioactivity of tin slag exceeds permissible limit adopted by Malaysia and many importing nation. In order to overcome this current problem, it is proposed to research for future application of tin slag as an aggregate replacement in polymer concrete. Moreover, policies for sustainable development of the construction industry and conservation of natural resources require the use of recycled and industrial by products of all kinds in buildings and constructions.

In line with the research theme seeking sustainability and green construction, this study utilized tin slag as aggregates with polyester binder to prepare tin slag polymer concrete (TSPC) samples. The objective was to find the optimum mixture ratio of aggregate/polyester that offered the best compressive properties such as strength and modulus. For this purpose, four aggregate sizes ranging from less than 1 mm to 3 mm were used. For each aggregate size, polyester ratio was varied from 20-40 %. Constituents were mixed in defined proportions and cast. Samples were subjected to compression loads to determine compressive properties. Finally, the effects of polymer variation on compressive properties of composite were discussed.

MATERIALS AND METHODS

MATERIALS

Polyester resin of orthophthalic type was chosen as binder because of its adhesive characteristics and lower cost. Methyl ethyl ketone peroxide (MEKP), as initiator, was mixed with the polyester resin. The proportion of initiator was 1% by weight of resin. Using mesh sizes categorised as fine, semi-fine, coarse and raw, the tin slag was sieved into four aggregate sizes: less than 1 mm, 1.4 mm, 2 mm and greater than 2 mm respectively. These were then oven dried at 100 $^{\circ}$C for 2 hours.

SAMPLE PREPARATION

Sample preparation was carried out under the guidelines of ASTM C 192/470. The details of sample types and mixture plan of the study are presented in Table 1.

Table 1: Sample Preparation Scheme

Group TSPC-SF			Group TSPC-F		
Type	Aggregate Size	Resin Ratio (% wt.)	Type	Aggregate Size	Resin Ratio (% wt.)
TSPC-F20	< 1 mm	20	TSPC-SF20	1.4 mm	20
TSPC-F25	< 1 mm	25	TSPC-SF25	1.4 mm	25
TSPC-F30	< 1 mm	30	TSPC-SF30	1.4 mm	30
TSPC-F35	< 1 mm	35	TSPC-SF35	1.4 mm	35
TSPC-F40	< 1 mm	40	TSPC-SF40	1.4 mm	40
Group TSPC-C			Group TSPC-R		
Type	Aggregate Size	Resin Ratio (% wt.)	Type	Aggregate Size	Resin Ratio (% wt.)
TSPC-C20	2 mm	20	TSPC-R20	> 2 mm	20
TSPC-C25	2 mm	25	TSPC-R25	> 2 mm	25
TSPC-C30	2 mm	30	TSPC-R30	> 2 mm	30
TSPC-C35	2 mm	35	TSPC-R35	> 2 mm	35
TSPC-C40	2 mm	40	TSPC-R40	> 2 mm	40

The aggregates and polymer were weighed according to pre-defined proportions. MEKP was mixed with polyester to finalize the resin composition. In the mixing stage, tin slag and polyester were poured into a bucket and thoroughly stirred for five minutes to ensure that the mixture was homogeneous. The mixture was then poured into 50 mm diameter PVC moulds. A bandsaw cutter was used to cut the specimens to 100 mm length after being cured for three days.

TEST METHOD

Load tests were performed using 600 kN Instron universal testing machine conforming to ASTM C579-01 developed for compression testing of polymer concrete. Figure 1 shows a specimen being placed between compression plates to allow for effective stress transfer across the specimen. The loading rate was set to 1 mm/min. Stress-strain response was recorded using software synchronized with compression testing machine.

Figure 1: Compression Test of TSPC

RESULTS AND DISCUSSION

COMPRESSIVE PROPERTIES

The primary aim of the study was to determine the highest values of strength and modulus across sample groups that vary in aggregate sizes. The data collected produced from the tests that highest values of both maximum compressive load and deformation at maximum load are for the finest size group (less than 1 mm) which corresponds to sample type TSPC-F. The values are 116.57 kN and 5.35 mm for load and deformation respectively. For the semi-fine group, the maximum compressive load is 112.58 kN and deformation is 5.21 mm. The highest values of load and deformation for the coarse and raw groups are: 87.49 kN, 4.71 mm and 60.88 kN, 3.73 mm respectively. The results for the highest performing specimens are summarized in Table 2.

Generally, the curves produced from the tests show a linear trend for test samples with optimum resin ratio or near to optimum value before being translated into a parabolic trend. This indicates that the load transfer is direct and the composite delivers a response that commensurate with the applied load. After the peak load, the behaviour of the finer size groups, i.e. fine and semi-fine sizes, is much more predictable and consistent than the coarse and raw sizes. These features of the curves assist in understanding that with the optimum resin ratio, the composite not only transfers load effectively but also leads to a gradual failure in the case of finer sizes (< 1 mm and 1.4 mm).

Also, from Table 2, with the increase of aggregate size, both the maximum values of load and deformation apparently decrease. In the same vein, the compressive strength and modulus values also reduce with the increase of aggregate size from less than 1 mm to around 3 mm.

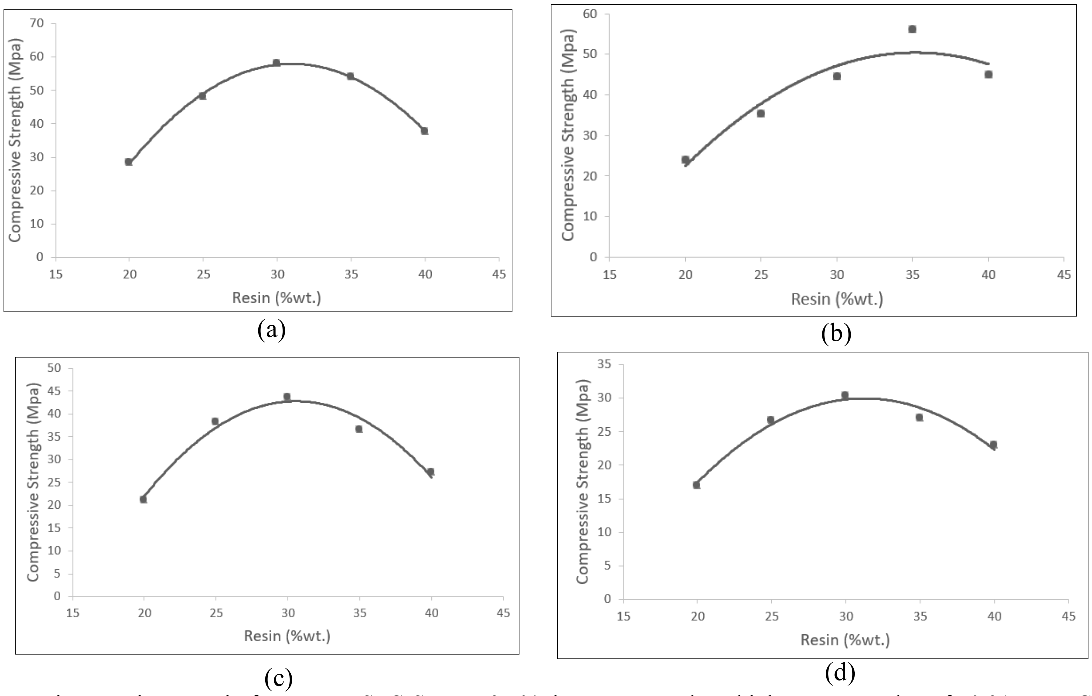
Table 2: Highest performing specimens from all groups

Sample Code	Compressive Strength (MPa)	Compressive Modulus (GPa)	Maximum Compressive Load (kN)	Maximum Deformation at Failure (mm)
TSPC-F30	58.21	2.49	116.57	5.35
TSPC-SF35	56.23	2.42	112.58	5.21
TSPC-C30	43.70	1.51	87.49	4.71
TSPC-R30	30.41	1.37	60.88	3.73

MIXTURE PROPORTION

Figure 2 show the curves obtained by plotting the strength and resin ratio percentage by weight. The values mentioned are statistical average of three results of identical specimen type. It is important to note that the curves follow a parabolic trend that emphasizes that an optimum mixture ratio is possible for each aggregate size. For fine size group, the optimum mixture ratio is found to be 30 % of resin and 70 % of aggregate. This mixture ratio gives the stress value of 58.21 MPa. This value is also the highest across all groups. The high performance of the finest size sample type is attributed to the effective bonding of binder with aggregates because of the higher surface area provided by the finer size aggregates. Additionally, the higher amount of resin consumed, i.e. 30 % also contributes to this performance.

Figure 2: Graph of compressive strength versus resin ratio; (a) group TSPC-F, (b) group TSPC-SF, (c) group TSPC-C and (d) group TSPC-R



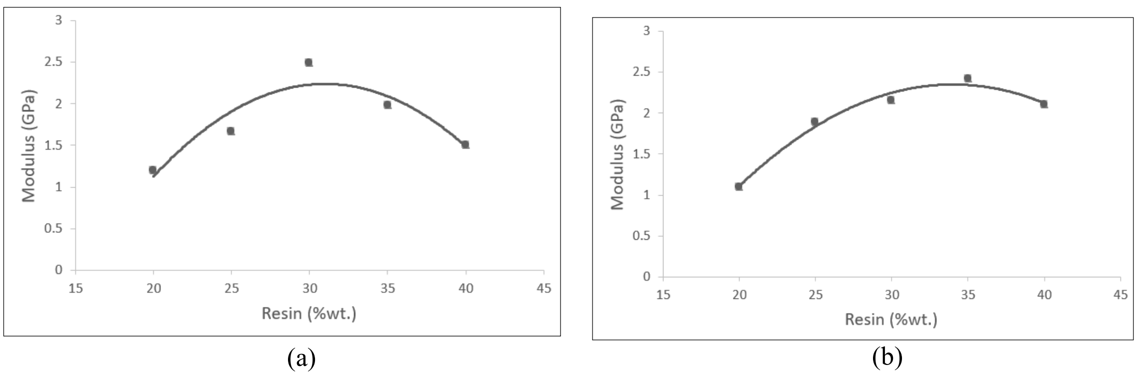
The optimum mixture ratio for group TSPC-SF was 35 % that corresponds to highest stress value of 50.21 MPa. Group TSPC-C graph shows the optimum mixture ratio of 30 % for stress value of 41.60 MPa whereas group TSPC-R exhibit optimum mixture ratio of 30 % for stress value of 29.89 MPa.

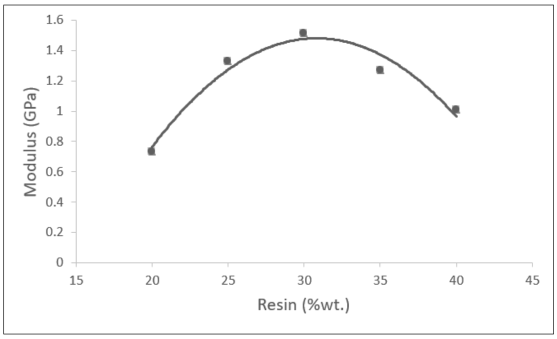
A similar trend is obvious for modulus values that can be seen in Figure 3. Resin ratio of 30 % is giving modulus of 2.25 GPa for group TSPC-F. In group TSPC-SF, modulus value of 2.39 GPa is highest against 35 % resin content. Group TSPC-C exhibit highest value of 1.45 GPa for 30 % of resin ratio while for group TSPC-R, values of resin ratio and modulus are 30 % and 1.31 GPa respectively. Table 3 summarizes the optimum resin ratio for all groups and sizes both in case of compressive strength and modulus.

Table 3: Highest performing specimens from all groups

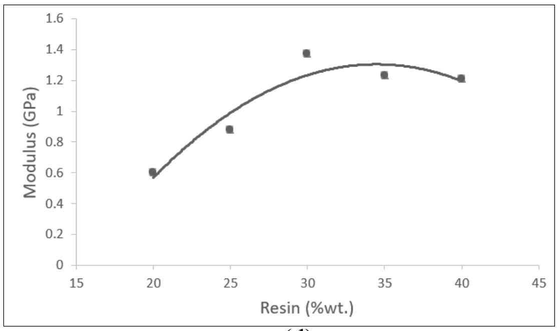
Compressive Strength Case (MPa)		Modulus Case (GPa)	
Group	Optimum Resin Ratio	Group	Optimum Resin Ratio
TSPC-F	30	TSPC-F	30
TSPC-SF	35	TSPC-SF	35
TSPC-C	30	TSPC-C	30
TSPC-R	30	TSPC-R	35

Figure 3: Graph of modulus versus resin ratio; (a) group TSPC-F, (b) group TSPC-SF, (c) group TSPC-C and (d) group TSPC-R





(c)



(d)

Another important thing related to finer sizes (<1 and 1.4 mm) is the linearity shown by curves of stress and modulus in the range of 30-35 % resin ratio. This trend is markedly different from the curves of larger aggregate sizes. It shows that the finer sizes are more efficient in interaction of aggregate and resin to deliver highest results than coarser sizes. Clear curves obtained for finer sizes show that the upward and downward trends are pretty sharp around optimum resin ratio that indicates that with the decrease in aggregate size, optimum value will get more precise and definite. The initial linear behaviour is an indication that in case of finest size the interaction of resin and aggregate is optimum enough to yield effective load transfer across two phases.

DISCUSSION

The results are consistent with previous research performed on optimum mixture ratio of polymer concrete. An optimum mixed ratio points out a proportion where properties are highest and the constituents phases of composite are effectively cooperating to deliver desired results. It is apparent from data analysis that an optimum mixture ratio of aggregate/binder exists across all aggregate size. Below this resin ratio, content of binder is not enough to coat the aggregates due to ensure a layer of soft phase between aggregates to efficiently transfer applied load. In case where resin content is more than optimum value, effective load bearing area will be reduced by the presence of inter-particle pores thereby decreasing the values of stress and modulus. In addition, higher resin content may also form soft zones in inter-particle spaces within composite hence deliver a response different form the dense particle-filled area.

CONCLUSION

This study made use of tin slag aggregate, a by-product of tin smelting, impregnated in polyester binder to prepare a polymer concrete samples. Four aggregate sizes were used, and resin ratios varied from 20-40 %. Samples were cast in PVC moulds and subsequently cut into a specified dimension and size. These samples were tested under compressive load using universal testing machine to determine the compressive strength and modulus. The primary findings of the study are summarized below:

1. The highest mechanical strength and modulus were found to be associated with the finest size, i.e. less than 1mm. The strength was 58.21 MPa and modulus value of 2.49 GPa. This can be attributed to the higher bonding area provided by the finest size. Resin/aggregate ratio was 30:70.

2. An optimum ratio of resin content exists for all aggregate size. Below and above this optimum point, mechanical properties decline thereby confirming the proposition of earlier studies performed. Optimum ratio varies between 30-35 % for all sizes tested in the study.
3. In general, with the increase in aggregate size, mechanical properties see a downward trend. This is because of both inadequate impregnation of aggregate and higher porosity associated with larger size aggregate. Another aspect is of lower density mix resulting from larger aggregate size.

Future work may concentrate on preparing a gap-graded mix to reduce the porosity and prepare a mix of higher density. Also, aggregate porosity effects the mechanical strength of the polymer concrete by acting potentially as crack initiation sites. Porosity studies may be carried out to determine its influence on mechanical properties or to understand feasibility of tin slag aggregate as structural grade aggregate. In addition, the promotion of green material utilization was also able to enhance sustainability construction development.

The authors would like to thank Universiti Teknologi Malaysia for funding this research and UTM Research Management Centre (RMC) for managing the research activities under Vot 03G89 and 15J32.

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