Optimization of Compression Strength by Granulometry and Change of Binder Rates in Epoxy and Polyester Resin Concrete

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ABSTRACT: Polymer concretes are composite materials comprised of two or more different materials. The fillers are compounds such as resin, hardener, accelerator, colorant, or matrix structure reinforcing materials. When it is considered as a building component for the body of a machine tool, machine or application, different compounds are prepared for the target application. By means of an appropriate design, production and tests that can resist the working conditions, it is possible for any composite to obtain the desired result. For this purpose, it is necessary to determine many mechanical properties. The pressure strength is therefore a basic feature to know. Within the framework of this study, the change in pressure strength was elaborated on the basis of the different aggregate distribution and binder rates designed on the standard cement granulometric curves. The used binders and fillers were polyester and epoxy resin and quartz respectively. The results comply with the literature, and it was found that an appropriate mixture optimization is possible for the desired strength.

KEY WORDS: polymer-matrix composites (PMCs), mechanical properties, mechanical testing, thermosetting resin.

INTRODUCTION

PORTLAND CEMENT BINDER concrete is a building material known worldwide with its wide range of applications. This low cost material has admittedly a good strength. However, it has some unwanted features like poor bending, tensile strength, high porosity, long curing time, shrinking, stretching, moisture sensitivity, and exposure to chemicals and other abrasives. In the years of war when it was hard to supply metal materials, it was suggested to use cement concrete instead of cast iron and welded construction in the machine tool manufacturing. It has a very high thermal stability compared to that of the metal materials, but due to the above mentioned disadvantages, no development has been scored for its use as a machine tool body, while the articles and studies have continued to find a high quality compound [1,2].

Though cast iron and steel materials were still used as traditional body materials in machinery and machine tool constructions, attempts were continued to discover new materials that could be used as a machine tool body. By the 1970s after the introduction of

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cement concrete, new concrete compounds emerged as alternative materials for machine tool body manufacturing, particularly as a result of the improvements in artificial resins. The studies on epoxy resins were the starting point of research on epoxy resin polymer concrete composites [3]. In the field of civil engineering, a number of very important improvements and developments have been realized for the use of Portland cement as a result of improvements in its strength and other disadvantages as well as the developments in polymers and their use with concrete technology [4].

The polymer concrete is a composite material comprised of aggregates in a polymer matrix [5]. For the composites that do not contain Portland cement, a number of different types, feature and applications for polymer concrete are presented [6,7]. Some studies have been carried out within the framework of the Japanese Industrial Standards (JIS) with regard to the manufacturing methods for concrete samples, test methods on pressure, bending and tensile strengths and the working life of polyester resin cements [8]. The studies on the factors effective on the strength and curing of polymer concrete [9] have been performed by classifying the polymer concrete (PC), polymer cement concrete (PCC) and the polymer impregnated cement (PIC) in order to describe coverage of such studies [10].

Responses of the surface grinder body made of polymer concrete and cast iron with approximately equivalent dimensions under the thermal effect were comparatively studied [11]. The axial bending-frequency relation was examined between a structure of the mixture of epoxy resin and granite aggregate and a structure of cast iron material [12]. The effects of vibration and noise formation on the body of a lathe bench were examined on the models formed by welded construction, cement concrete, and polymer concrete structures [13]. As the body component in the cutting machine tools, the polymer concrete materials with epoxy EP, methylacrylate MMA and urea formaldehyde UP resins were compared with the welded structure and cast iron [14], and some studies were carried out in regard to their mechanical characteristics as the machinery building components [15]. The technological developments in polymer concretes [16], polymer concrete production technology and the results obtained from studies on the machinery [17], the pressure and bending strength, elasticity, shrinking and interactions with sulfuric acid were studied [18].

On the polymer concretes, various studies were carried out, including the matrix structure, thin or coarse grain aggregate types, binders and distribution in mold space, formation of loose or dense structure and optimization of mixture rates [19,20]. Standard techniques were defined for preparation of the polymer concrete mortars with resin and filling materials, casting samples, and pressure strength operations [21]. The polymer concrete is a material with highly changeable characteristics with variable distribution of such composite materials as polymeric binder, aggregate, etc. For the polyester and epoxy resin polymer concretes, a reliable estimated mathematical pattern was presented for optimization with process change suitable for the mixtures [22]. Glass-reinforced composites with high compressive strength were prepared using two different epoxy resins and various curing agents such as matrix and S-glass fibers (S-GF) as glass reinforcement. Results for tensile, compression, bending, impact, hardness, distortion temperature, glass transition temperature and their association with free volume were reported for the composites, with the matrix of high material density and low free volume displaying distinct superior mechanical properties. The curing agents also have a significant effect on the compressive strength of composites [23]. In this article a study on the tensile, flexural, compression, and impact strength of granite powder–epoxy composites on toughening epoxy with unsaturated polyester and unsaturated polyester with epoxy resin has been assessed. The water absorption studies revealed that an increase in the strength of the composites showed a positive toughening effect. The morphology study has also been carried out in order to study the interfacial region in the composites [24]. Good theoretical composite models have been developed to address the modulus as a function of filler volume fraction and tensile strength as a function of time. A simple parallel strain composite tensile strength model is developed from the different tensile strength components in the composite. It is clearly shown that the new generalized tensile strength model developed in this study gives a much better fit of four sets of tensile strength data than the Turcsanyi model, the Dibenedetto model, and a second-order polynomial model. This result applies equally for data that shows a clear maximum as well as data where the tensile strength decreases steadily from the tensile strength of the matrix itself [25].

Emphasis was particularly put on the literature studies carried out on the building materials and their mechanical features. However, many studies are observed on the different applications. Each application requires some specific conditions, including environment, reacting loads, requirements of use, material features or mechanical, physical, chemical, optical and similar factors. A material can give different results from one application to another. The characteristics of polymer concrete can vary considerably in different applications in respect of the type, quantity, production method, etc. In this context, it is important to prepare the material with the most appropriate solution in consideration of all the conditions and changes that may be experienced in practice for the component to be manufactured. The specific characteristics of each compound in the mixture would be partially reflected on the structure formed at the end of composition.

DESIGN OF EXPERIMENTS

This study is carried out to determine if a targeted value of pressure strength in a building material can be obtained by means of changing the filling material granulometry and binder rates. If this could be done, it would be possible to use any desired building component for the same mechanical feature. The distribution of grain size of structural fillers could take place in two ways. The first one is the method, called Feret's Triangle, where the material distribution is divided into three groups and classified as fine, medium, and coarse. In this classification, the evaluation is made as to include many grain sizes in the related range. The second one is the grain size distribution of aggregates determined through the granulometric compound definition EN 12260. As this allows making a better evaluation by grouping different grain sizes at small ranges, it seems better to use the granulometric curves for the grain size distribution.

As a new approach, the distribution curve of a total of seven different aggregates was drawn with additional new curves designed in and around the ideal zone on the granulometric curves of standard cement concrete, as the existing intervals were more narrowed, and it was worked on the epoxy resin [26]. In this context, the results for epoxy and polyester resins were comparatively presented, as the structures were elaborated to obtain the best pressure strengths of the polyester resin polymer concrete composites prepared with the appropriate binder rates and filling materials of different rates suitable for the described design of granulometric distribution.

MATERIALS AND METHODS

Many different resins are used in the polymer concrete materials. In practice, it is very difficult to use epoxy and polyester resins. Therefore, this study was preferably based on these resin types. The epoxy resin is a thermosetting material with two components that exist in fluid form at room temperature, and become solid with hardener. Due to their viscosities, they can solidify at low temperatures without any strain and cracks. The epoxy resin and appropriate hardener used in this study are 'Europox730' and 'XE305S' made by 'Schering Aktiengesellschaft, Germany', an industrial chemical manufacturer, considering that the said products have the best pot life and would give the most appropriate pressure and bending strength for our approach among the other epoxy mortars and epoxy concrete applications and resins and hardeners used in many other applications [27]. The polyester resin is, however, a condensation polymer of an alcohol and acid. The degree and velocity of hardening are controlled by accelerators and catalysts. It is the cheapest resin that can solidify at room temperature. Its disadvantages include unpleasant odor, shrinking, high exothermic reaction, difficulty of precise forming, formation of internal tension in manufacturing and the relatively low adhesion compared to epoxy. The polyester resin used in this study is 'Marshall 3522 unsaturated polyester resin; hardener and accelerator' [28]. The characteristics for resins and hardeners are given in ASTM D 1652-67, DIN 16911, DIN 16912, DIN 16945, DIN 51757, and DIN 51758.

The hardening process can take minutes to hours at room temperature without need to compression. It is necessary to know the best hardener and its mixing rates for a particular resin for the purpose of a perfect polymerization. The study was based on the resin rates up to maximum 30%. The adhesion features of fillers and resins, as they can reduce the actual costs, and improve such characteristics as hardness, strength, temperature, light stability, viscosity, chemical resistance, electrical resistance, conductivity, etc. The characteristics are affected by the natural, grinded or synthetic fillers. It should be very clean, dry and have an adequate strength, and not react with the resin and hardener. The rate of filler can be up to 90% of the maximum weight. As the polymer concrete characteristics are affected by the grain distribution, a good granulometry can provide high strength. Different aggregate sizes should be kept together to minimize air bubbles and obtain a dense structure. For this purpose, discontinuous granulometry can be used. If the air bubbles could be eliminated to provide a dense structure, it would be possible to obtain more durable products, and therefore the vibration is important, so that a vibrating table was used. The vibration was applied at 600 rpm for 15 minutes before gel formation on the basis of the pot life of 30 minutes for epoxy in casting. For the polyester resin, the time of gel formation is 10 minutes with a shorter time of vibration. The controlled pressure force is also very important when it solidifies at low temperature, as attention should be paid to internal tensions, but it was not the case for this study. The chosen filler is quartz, as it is usually proposed as an aggregate, and has good strength and adheres to the epoxy resin in a better manner. The supplied aggregate was divided into groups at the grain sizes of 0.25, 0.50, 1.0, 2.0, 4.0, 8.0 mm by means of a set of square wire mesh test sifters, sieve analysis and sifter shaking machine according to ISO 3310-2, ISO 3310-1, ASTM C 136, ASTM C 137, EN 12620, ACI 613 64, DIN 1045 standards. Figure 1 shows the mixed aggregate granulometry curves based on the maximum grain size of 8.0 mm with the newly defined seven distribution groups to examine the actual status in a detailed distribution, while Table 1 covers the percentages of such groups that pass through sieves. In the standard granulometry curves, the grain size distribution rates of the samples that underwent the sieve analysis are defined for the aggregate distribution as very good between the curves A and B, and as usable between the curves A and C. Accordingly, the

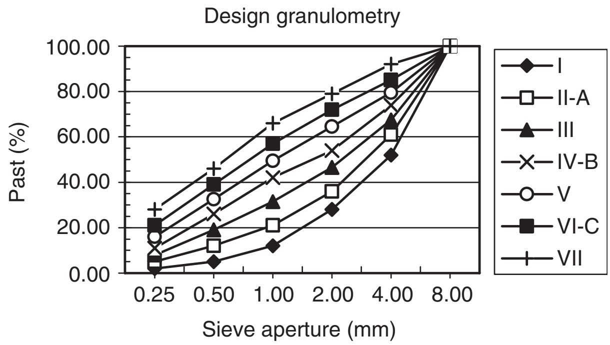

Figure 1. *Design aggregate granulometry curves.*

Table 1. Covers the percentages of such groups that pass through sieves.

Sieve number (mm)	Groups						
	I	II	III	IV	V	VI	VII
8	100	100	100	100	100	100	100
4	52	61	67.5	74	79.5	85	92
2	28	36	46.5	54	64.5	72	79
1	12	21	31.5	42	49.5	57	66
0.5	5	12	19	26	32.5	39	46
0.25	2	5	8	11	16	21	28

design curves II, IV and VI among the curves shown in Figure 1 can be considered according to the standard curves A, B and C as I below ideal zone, III within ideal zone, V within usable zone and VIII above usable zone. In this case, the different grain size distributions and resin rates in all the zones from I to VII in granulometric distribution would be studied in addition to the change of pressure strength for the composite material produced by us.

The equipment required for dehumidification includes an autoclave of 250°C, balance with an accuracy of 0.5 g, dust and gas masks, appropriate filters, sheet collection containers, plastic vessels, plastic garbage boxes, plastic measuring containers, wire brushes, shovels, mixers, trowels, scrapers, rubber gloves, safety gloves, and chemical solvents for cleaning the wastes.

The dimensions of pressure test samples were determined as Ø50 × 100 mm for the filler of maximum 8 mm grain size in the polymer concrete and its applications as per DIN 51290 – Section 3, ISO 2736-2, ISO 4012. According to the working sample of filler and epoxy resin comprising of 0–0.2 mm and 0.6–1.2 mm quartz sand mixture of the resin manufacturer as per DIN 1164, the binder rate was 12–17%, and the peak pressure strength exceeded 90 N/mm^2 particularly in the percentage of 14.3% [27]. Every parameter is important in the course of casting. Therefore, the acceptable binder rates are 16, 18, 20, 22, 24, 26, and 28% for the polyester resin, and 14.3%, 18%, and 22% for the epoxy resin, as the fillers could be completely moisturized without any additives upon the preliminary studies appropriate for our own design structure. The filler is quartz for the remaining section.

This study used molds made of plastic questamide material, as they give much better results. The mold remover can be applied for one or more times on the clean surfaces. It is made ready for use by polishing after waiting for 15–30 minutes. The materials were used as solution at any desired places as such applications like fluid polyvinyl alcohol PVA, polyvax SV-S or PVA tape.

The test samples were prepared as 'pressure test samples', total 105 pieces including 5 pieces for each of 7 groups with 3 binder rates for epoxy resin, and total 147 pieces, including 3 pieces for each of 7 groups with 7 binder rates for polyester resin. Though the material cured within 2 hours after casting, they were removed from the mold 24 hours later, and all the samples were left at room temperature for a total 21 hours before the pressure tests were carried out. The pressure tester EL 31-3275/01 ADR 2000 made by Ele Int. Ltd. UK was used for the pressure tests.

RESULTS

At the end of the pressure tests carried out on the produced samples with polyester and epoxy resins, the reacting load and strain values were given as 'kN and daN' and 'daN/cm^2' respectively. The distributions were cumulatively given for each rate and group in the form of pressure load tables, strain values, and all curves.

Epoxy Resin

Table 2 shows the 'compression load values of samples prepared according to the granulometric distribution groups from I to VII for epoxy resin binder + quartz filler' [26].

Table 2. Compression load values of samples prepared according to the granulometric distribution groups from I to VII for epoxy resin binder + quartz filler [26].

	Groups						
% Epoxy + % quartz	I	II	III	IV	V	VI	VII
%14.3 + %85.7	75	92	141	149	166	177	115
	51	116	94	158	158	155	113
	66	104	130	170	179	174	132
(compression loads, kN)	89	145	149	169	126	126	108
	128	116	154	172	156	160	78
%18 + %82	125	163	182	188	174	174	191
	118	165	170	185	171	174	192
	131	160	177	178	188	196	196
	84	124	168	182	187	186	97
	90	155	176	182	176	186	149
%22 + %78	75	92	141	149	166	177	115
	51	116	94	158	158	155	113
	66	104	130	170	179	174	132
	89	145	149	169	126	126	108
	128	116	154	172	160	160	78

Figures 2 and 3 demonstrate the 'changes in compression strength according to the granulometric distribution groups with epoxy resin % + quartz filler % samples', and the 'changes in compression strength according to the granulometric distribution groups with epoxy resin % + quartz filler % all samples', respectively.

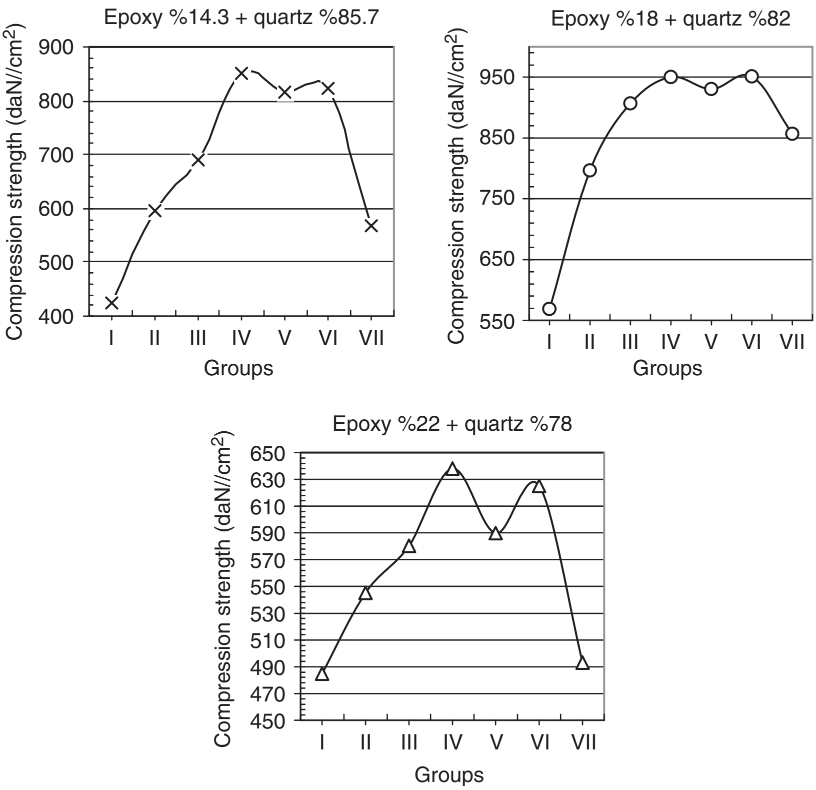

Figure 2. *Changes in compression strength according to the granulometric distribution groups with epoxy resin % + quartz filler % samples, respectively [26].*

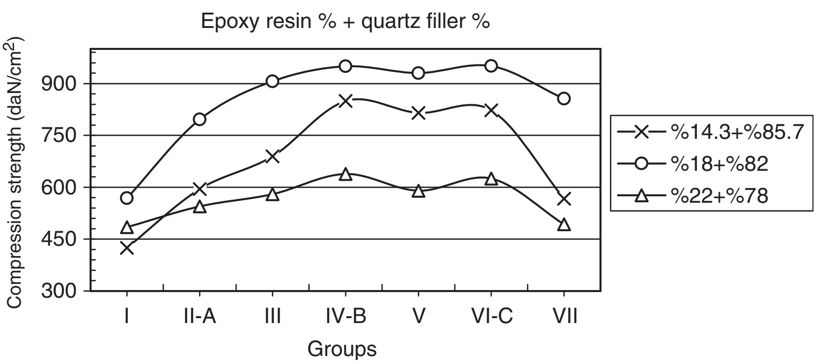

Figure 3. *Changes in compression strength according to the granulometric distribution groups with epoxy resin % + quartz filler % all samples, respectively [26].*

In the studies carried out on the epoxy resin, the highest value of compression strength was obtained as 951 daN/cm^2 for the structure with a binder-filler rate of 18–82%. The highest values are listed in this curve as VI and IV, followed by V, III, VII, II, I. Therefore, the granulometric curves for standard cement concrete demonstrated the highest values on Curve B with IV and on Curve C with VI. Thereafter, the centers of usable zone and ideal zone became V and III respectively. Apart from these points, there is a reducing trend. With the resin rates of low 14.3% and high 22%, it demonstrates a similar distribution as IV with B and VI with C for both.

Polyester Resin

Table 3 shows the 'compression load values for the samples prepared according to the polyester resin binder + quartz filler and the granulometric distribution from I to VII'. Figure 4 however demonstrate the 'changes in compression strength for the polyester resin binder % + quartz filler % samples and according to the granulometric distribution groups', while Figure 5 graphically represents the 'changes in compression strength for the polyester resin binder % + quartz filler % all samples and according to the granulometric distribution groups'.

In the studies on polyester resin, two important zones are observed. The first one, which can be named as the 'economic zone', is the curves with binder rates of 16, 18,

Table 3. Compression load values for the samples prepared according to the polyester resin binder + quartz filler and the granulometric distribution from I to VII.

	Groups						
Polyester % + quartz %	I	II	III	IV	V	VI	VII
%16 + %84	2930	4860	5030	8940	7080	6780	6950
(compression loads, daN)	3160	6480	9600	6740	7950	7340	4350
	3080	5670	10420	7670	7390	7890	8430
%18 + %82	2820	11320	12400	11070	4680	9090	7920
	3680	10630	12660	11060	6850	8700	8930
	4030	10390	11960	10060	8680	7960	7980
%20 + %80	4440	5180	8130	9960	6310	8120	5280
	4310	6620	8900	8970	6090	8380	5590
	3120	5660	8760	8340	4950	8750	4950
%22 + %78	10810	11500	10300	11330	11380	11310	9520
	10950	11610	9920	11540	10820	10770	7830
	9740	11220	10870	10850	10600	10530	8230
%24 + %76	4460	11940	11810	12240	11690	12150	9210
	7700	12260	12630	11600	11350	8100	9540
	10830	12020	10210	11740	10910	9030	7920
%26 + %74	7673	8161	9768	10338	11070	10652	10338
	8355	7886	10711	9437	10840	10093	9864
	8230	8995	9882	10324	10855	10108	10321
%28 + %72	6814	7880	9344	10200	10530	10210	9122
	7048	7102	10400	11300	10380	10360	10090
	5872	6220	10530	10360	10820	10740	10070

and 20%. The second one, which should be called the 'uneconomical zone' for excessive use of resin, comprises of the curves formed by the rates of 22, 24, 26, and 28%. The first distribution is, in fact, the highest value of strength as 18%, which demonstrated a behavior similar to the epoxy resin, and could reach 628 daN/cm^2 with the Group III. At this point, the curves 16% and 18% remained below 18% in terms of strength. In this

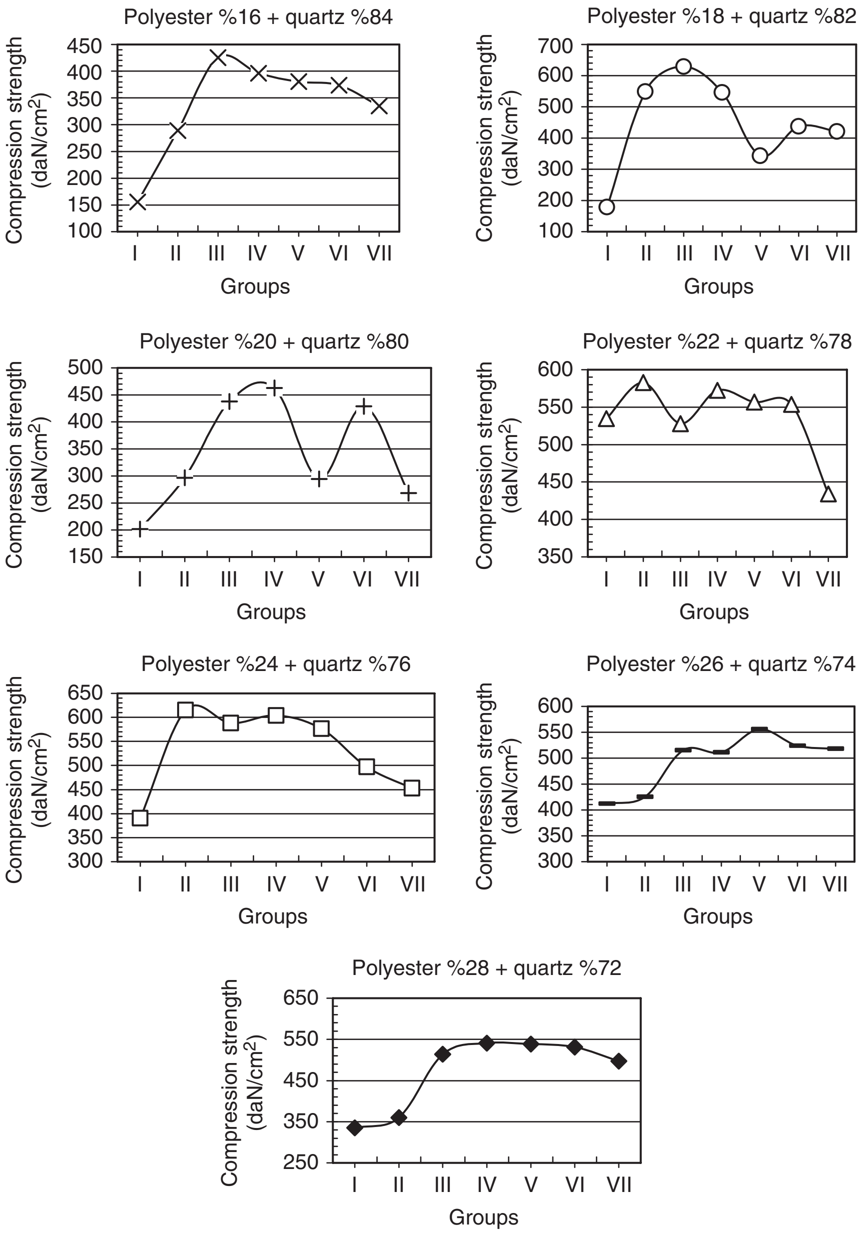

Figure 4. *Changes in compression strength for the polyester resin binder % + quartz filler % samples and according to the granulometric distribution groups.*

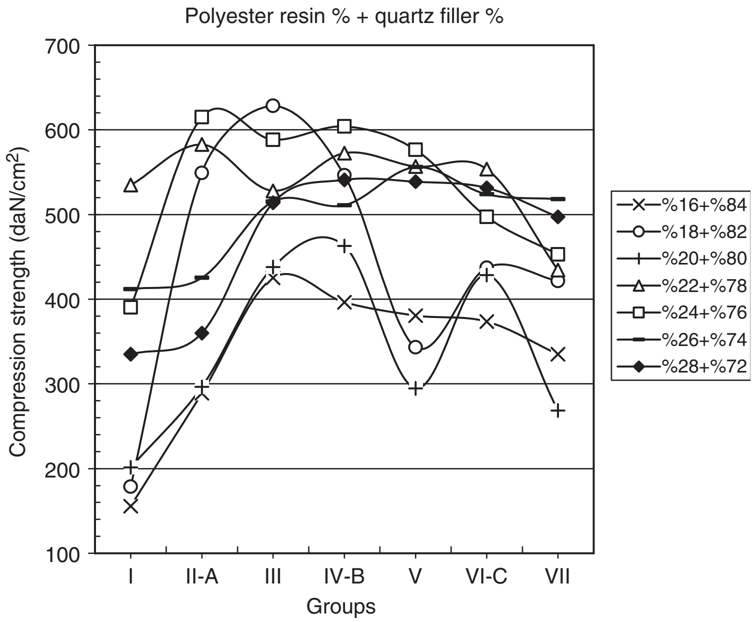

Figure 5. *Changes in compression strength for the polyester resin binder % + quartz filler % all samples and according to the granulometric distribution groups.*

case, the compound III with 18% is just the center of the ideal zone and takes place between A and B according to the granulometric distribution of standard cement concrete. For the other curves, 20% was obtained as the Curve B with the group IV, and 16% was obtained as the Curve B with the compound III. In the curves of the second uneconomical zone, the points apart from 22% I, II, VII were listed as II A, IV B, and VI C. Here, the distribution is almost horizontal. However, the highest values of strength are observed in the ideal zone. The curve of 24% was developed as II A, IV B, III, and V, and the curve demonstrated a very close trend, though the high strength value was below 18% and curve III. The other two resin rates of 26% V and 28% remained at low levels, though they scored peak at IV B.

DISCUSSION

The peak values of curves in the epoxy resin study could be used in development of an appropriate distribution of grain sizes in order to obtain a polymer composite structure that has the best pressure strength, as the granulometric distribution given for the cement concrete was realized in the B ideal and C usable zones.

For the polyester resin studies, it is interesting that the granulometric distribution given for cement concrete demonstrates the highest strength similarly between the ideal zones A and B, particularly with the low resin rates called the economic zone. Though the distribution extends up to the usable zone C for the increasing resin rates in the uneconomical zone, the overall appearance is that it could be used in the entire zone from A to C, particularly outside the distribution group V.

It is commonly observed in the epoxy and polyester resin studies that there is a continuous reduction in the distribution V, except the high rates of polyester resin. Though it is the center of the usable zone, one can say that the grain size distribution and rates used in this group caused formation of a compound that reduced particularly the pressure strength in the structure. This could be corrected to some extent by increasing the resin rate.

The resin and filler rates and granulometric distribution affect the polymer concrete characteristics, and so the pressure strength. The epoxy resin results in stronger composite structures compared to the polyester.

The studies have demonstrated that the pressure strength changes even depending on the type of resin used at the maximum filler rates, and could be increased up to 93%, for epoxy resin, with the additives that increase the moisturizing characteristics of mixtures. In this study, such additives were not used. Therefore, the curves show that the strength is similarly reduced at the low or high resin rates.

The mechanical features of polymer concrete varies depending on the metallic materials. The variances of strength values among groups can be attributed to the fact that the strength of polymer concrete depends on very different parameters, and it has not got a homogeneous and isotropic structure. For this reason, it is necessary to obtain an environment suitable to the working conditions for each application, and perform any necessary analyses in details based on all the parameters effective on the characteristics of polymer concrete. This study can be useful in guiding such analyses.

As a suggestion for further studies to be carried out, it is possible to work in the form of discontinuous granulometry or for a certain grain size. A furnished composite formation prepared with filler and steel or any other different material could be evaluated. The wearing features of such obtained composite structure could be searched. The behaviors of the existing structures under the heat cure could be elaborated. It is also possible to search their strengths at different loading velocities. Different parameters could be worked on, including prolonging agents, adhesion enhancers, paints, fibers and similar reinforcing materials, different resins, fillers, accelerators, and hardeners.

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