



EXPERIMENTAL STUDY ON COMPRESSIVE STRENGTH AND FLEXURAL RIGIDITY OF EPOXY GRANITE COMPOSITE MATERIAL

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Abstract

In Egypt, large quantities of coarse granite wastes are produced annually during the quarrying operations of granite rocks. This waste represents a potentially useful source of material for a variety of applications such as a filler material in epoxy granite composite material. In this work a new eco-friendly composite material studied as a substitute for machine tools traditional materials, like cast iron, to produce better efficiency with lower cost. This study aims to investigate the mechanical properties of granite epoxy composite by using the local epoxy (kemapoxy 150) and the granite residues in the Egyptian quarries. The investigated processing variable was epoxy content, and the mechanical characterization were carried out by compressive and flexural tests according to the ASTM standard method B. Commercially available, Aswan red granite was procured, crushed, and sieved to three size ranges from 0.150 to 8 mm, respectively. Epoxy ratios of 80:20, 85:15 have been used with granite aggregate size mix with small, medium, and coarse size proportions of 50:25:25 respectively for preparing the specimens with granite granular size range (0.150-8) mm. The results show that Epoxy granite composite with granite to epoxy ratio of 80:20% wt. induced the highest compressive strength (72.15 MPa) while the composite with the ratio of 85:15% wt. induced the highest flexural strength (20.1 MPa). Epoxy granite composite show superior results with respect to cement concrete, polyester concrete, and natural granite.

Keywords: Epoxy-Granite; Composite materials; Compressive strength; Flexural rigidity; Resin ratio

1. Introduction

Eco-friendly, high strength, low weight, low cost, Recyclability, and durability are essential considerations in the choice of modern products. recently composite materials with their inimitable, feature-rich properties have become a trend in the industrial trend to maximize materials usage and economics of industrial production process and production techniques. In this respect, the focus on the technical development of highly competitive constructional composite materials needs to be continuously sharpened. Another important cause for this trend is the usage of composite materials like epoxy granite composite would result in economic optimization of granite industry wastes, which are produced in large quantities in quarries. The convenient use of granite wastes will render them as useful profitable products. Pollution will be reduced and natural resources will be conserved [1]. Granite reinforces Epoxy composite is the material produced using high strength coarse and fine granite powder generated as a waste from quarrying and mining granite rocks[1] as a filler material. The major desired factor which affected on structure and material of machine tools' properties are high structural stiffness, excellent damping, and low thermal sensitivity[2]. Therefore, the produced material is expected to be ideal to develop alternative materials for machine tools structures with excellent flexible operation performance[3],[4]High productivity, and low cost [5]-. Table 1.

Table 1. Comparison of the properties of steel, cast iron, and polymer concrete [5]

Properties	Units	Steel	Grey cast iron	Polymer concrete
Density	g/cm ³	7.85	7.2	2.1-2.4
Compressive strength	N/mm ²	250-1200	350-450	140-170
Bending strength	N/mm ²	400-1600	150-400	25-40
Young's modulus	KN/mm ²	210	80-120	30-40
Heat-transfer coefficient	W/(m*K)	50	50	1.-20
Thermal expansion coefficient	μm/(m*K)	12	10	12-20
Specific heat	kJ/(kg*K)	0.45-0.5	0.5	0.9-1.3
Logarithmic decrement		0.002	0.003	0.02-0.03
Cost	EUR/dm ³	7.67	5.11	2.56
Manufacturing energy demand	MJ/dm ³	160	120	25

Tsung-Chia Chen et al. [6] verified the effectiveness and the feasibility of the fabrication of the machine tools structure like milling machines using epoxy granite composite and show improvements in the manufacturing process. Parbhu Raja et al. [7] investigated that replacing the cast-iron base of a vertical machining center with an epoxy granite composite base and find an improvement in the machine products' quality and productivity. Shanmugam et al. [8] use epoxy-granite composite made of large granite aggregates as a filler material in the machine

tools and prove it as an acceptable and reliable solution for machine tools structures. Antonio Piratteli et al. [9] investigated the effectiveness of using the epoxy content ratio of 15 and 20% wt. and granite aggregates rate of (50% large and 50% small) on the compression strength of epoxy granite composite. The results indicate a significantly higher magnitude of compression strength relative to comparable commercial brands of machine tools made from traditional materials [9]. Subhash et al. [10] investigated the effectiveness of using granite powder as a reinforcement material at epoxy granite composite in the weight, strength, and surface finish. they found that epoxy granite composite with resin ratio between 60% to 70% is the most suitable composite for structural and engineering applications like machine tools structure. Maria Luiza et al. [11] showed that epoxy granite composite had satisfactory physical and mechanical properties, like resistance to temperature oscillations, and high resistance to wear and impact. Selvakumar et al. [12] carried out numerical, analytical, and experimental studies on specimens of steel, cast iron, and epoxy granite at constant stiffness to compare the properties of structures from these materials more precisely. They observed that, at the same stiffness, epoxy granite composites offer high damping performance with significant weight reduction, as induced vibrations were dampening out at a faster rate in case of epoxy granite composite compared to cast iron and steel specimens. Balakrishna et al. [13] investigated the mechanical properties such as compressive, flexural, and tensile strength and the vibration behavior of epoxy granite composites with and without using additional particles of cast iron as filler materials. It was found that the cast iron particulates percentage affects damping and mechanical properties of the produced composite. they found that compressive strength increases with the increase in the reinforcement cast iron particulates, while damping, tensile and flexural strength decrease with increasing the cast iron reinforce particulates [13]. Deepak et al. [14] investigated the mechanical properties of epoxy granite composite such as compressive and flexural strength, damping properties, and modulus of elasticity. The results showed that the density of epoxy granite composite three times lower than the density of cast iron with better vibration damping performance and less manufacturing time. P.Mani et al. [15] presented a comparative analysis study on epoxy concretes, polyester concrete, and conventional cement concrete composites with the same aggregate in each composite They studied Mechanical properties such as compressive, flexural, tensile, and impact strength and found that both epoxy and polyester concrete show properties far superior to conventional concrete while epoxy concrete showed superior properties to polyester concrete. In this study an investigation of the compressive and flexural properties of epoxy granite composite material according to ASTM-579-01 and ASTM-C580 standard were preformed using Egyptian granite as a reinforced material, local epoxy (kemapoxy 150) as a matrix material to produce epoxy granite composite material for the industrial application. Granite to the epoxy ratio of 80:20 and 85:15 % wt. with granite granular size range (0.150-8) mm were selected in this study.

2. Experimental Details

2.1 Materials

In this work a mixture of course and fine granite particles were used as a reinforcement. Crushed granite is an intrusive volcanic rock (igneous rocks) that consists mainly of orthoclase, quartz, and mica with coarse crystalline grains [16]. Granite rubble is considered to be a non-reactive aggregate, however, depending on the quarry, granite may have various impurities including harmful minerals containing active SiO₂ [17] . The used coarse and fine granite powder was brought from the Aswan area in southern Egypt, which generated from quarrying and mining granite rock. The chemical composition of the used granite is shown in table 2.

Table 2: XRF Commercial analysis of the used granite [18].

Element	ms%	mol%	Sigma
Al	8.5000	10.8068	3.7957
Si	47.6969	58.2576	4.1407
k	11.2912	9.9059	3.4859
Ca	3.5633	3.0498	2.9038
Ti	1.9455	1.3933	1.4508
Mn	1.1757	0.7342	1.0394
Fe	25.6899	15.7803	1.0007
Zn	0.1375	0.0722	1.2422

Commercial diglycidyl ether of bisphenol A (DGEBA) (kemapoxy 150)[19], which has been supplied by chemicals for modern building international (CMB) Co., Egypt, with epoxide equivalence weight in the range of 182–196 g/equiv. and density at 25°C (1.11 g/cm³) which able to act as a lubricant in its liquid phase. With two components, solvent-free and non-pigmented liquid epoxy were used as a matrix material. It is utilized as a coating where outstanding mechanical stresses and chemical resistance are required. It complies with ASTM C 881 & ES 1382[20]. The diglycidyl ether of bisphenol-A (DGEBA) is produced by reacting bisphenol-A with epichlorohydrin in the presence of a basic catalyst [21], [22].

2.2 Samples Preparation

Granite waste and fine powder granite which are generated from quarrying and mining granite rocks collected, crushed, and sieved in mineral processing laboratories, in the Mining and Metallurgical Engineering Department, Faculty of Engineering, Assiut University. Stone Jaw Crusher has been used for crushing granite slabs into aggregates less than or equal to 8 mm. Roll Crusher was used for crushing granite aggregates into small aggregates and Disk Mill for grinding the small aggregates to get fine granite aggregates. Granite aggregates are sieved after each crushing step. Granite aggregates are categorized into three groups as 0.150-to 1-mm fine grain, 1-to 5-mm middle grain, and 5-to -8mm coarse grain. The amount of the granite aggregates ratio is given in Table 3.

Table 3: Aggregate Size Mix

Aggregate Size	Fine (0.150-1) mm	Middle (1-5) mm	Coarse (5-8) mm
weight percentage	50 Wt.%	25 Wt.%	25 Wt.%

Granite granules were washed well with water to get rid of dust and residues. Then the granite was dried from the water residual. Acrylic molds were prepared according to standard ASTM-579-01 and ASTM-C580, molds sprayed from the inside using a release agent for easy removal of the specimens. Component B (hardener) added to component A (resin) and mixed using a mixer for 3 minutes in the ratio of (2A to 1B) with mixer velocity of 300 r.p.m. [19] after that the filling material of the granite aggregates added to the mixture of epoxy and mixed again for 15 minutes to make sure of getting a homogeneous mixture of the epoxy granite composite. Granite aggregates were mixed with epoxy in two ratios of (85:20) % and (80:20) % by weight. Acrylic mold has been used for casting the specimens as shown in Fig. 1.

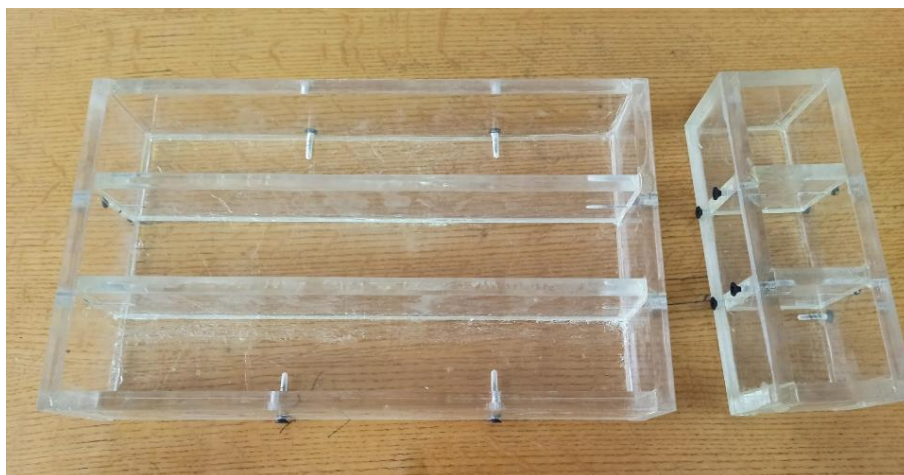


Fig. 1. Acrylic mold for compression, flexural, and damping spearmints tests

Fill the mold one-half full with epoxy granite [23], [24], shake the molds using vibration table for 10 minutes to remove entrapped air then fill the remainder of the mold and shake the mold again for another 10 minutes. Then, the composite was cured for 24 hours at room temperature. The produced specimen was then aged for seven days before testing to ensure that the composite is completely hardened [19]. Each sample has been labeled with specimen type and number.

The appropriate weight ratio of epoxy resin for preparing the epoxy granite composite with the selected granite granular size is determined according to the following equations to determine the minimum resin content (MRC%) [11].

$$\text{MRC}\% = \left(\frac{VV\% \times \rho_{\text{resin}}}{VV\% \times \rho_{\text{resin}} + (100 - VV\%) \times \rho_{\text{granite}}} \right) \times 100 \quad (1)$$

Where: The density of the granite used was 2.61g/cm³ and the density of the used granite (kemapoxy 150) was 1.11g/cm³, and,

$$VV\% = \left(1 - \frac{\text{dray apperent denisty of particals}}{\text{apperant denisty of granite}}\right) \times 100 \quad (2)$$

Where: Dray apparent density of partials was 1.915g/cm³, the density of granite was 2.61g/cm³

The value for the minimum resin content was found to be 13.37%, which represents the minimum percentage of the weight of resin needed to fill the void volume. However, in this study, 15% and 20% of resin were used in the formulation of epoxy granite composite as a margin of safety to obtain a cohesive composite of epoxy and granite. The granite epoxy composite manufactured specimens used in the conducted compression and flexural test acceding to ASTM standards are shown in Fig. 2.

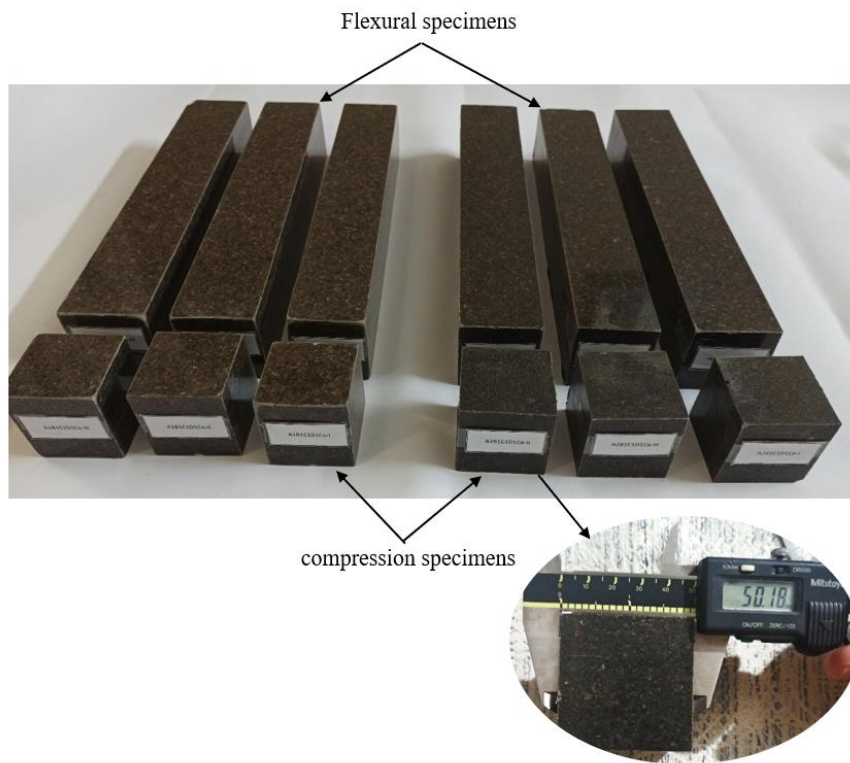


Fig. 2. Compression cubic and flexural beam test specimens of epoxy granite composed.

2.3 Compression test

The tests were conducted according to ASTM-579-01 Method B with the universal testing machine to determine the compressive strength of the epoxy granite composite.

Compressive test specimens were prepared, as cubes with the dimension of $(50 \pm_{3.0}^{+1.5})$ mm with a flat and smooth face as shown in Fig. 3. , each faces normal to each other and the angle between each face within the limit of $(90 \pm 0.5^\circ)$ and the tests was carried out using a universal testing machine M/C in Force and Material Metrology Laboratory, National Institute of Standards (NIS), Ministry of Higher Education and Scientific Research, Haram - Giza –Egypt.

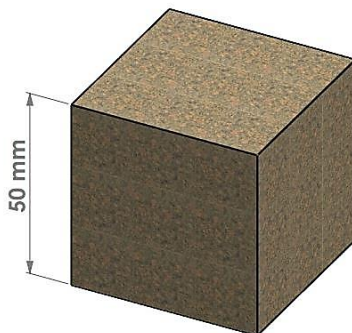


Fig. 3. The compressive strength test specimen

A Spherical bearing block with a diameter of more than three-time of the specimen width was used. the test set-up as shown in Fig. 4. The load applied continuously at the rate of (41 MPa/min) and without shock, epoxy granite specimen loaded till failure and compressive strength calculated according to the following formula [23]:

$$S = (W) / (L_1 \times L_2) \quad (3)$$

Where: S is the Compressive strength in (MPa), W is the Maximum load in (N), L_1 and L_2 are the cross-section dimensions of prism measured using micrometer with the accuracy of ± 0.02 mm.

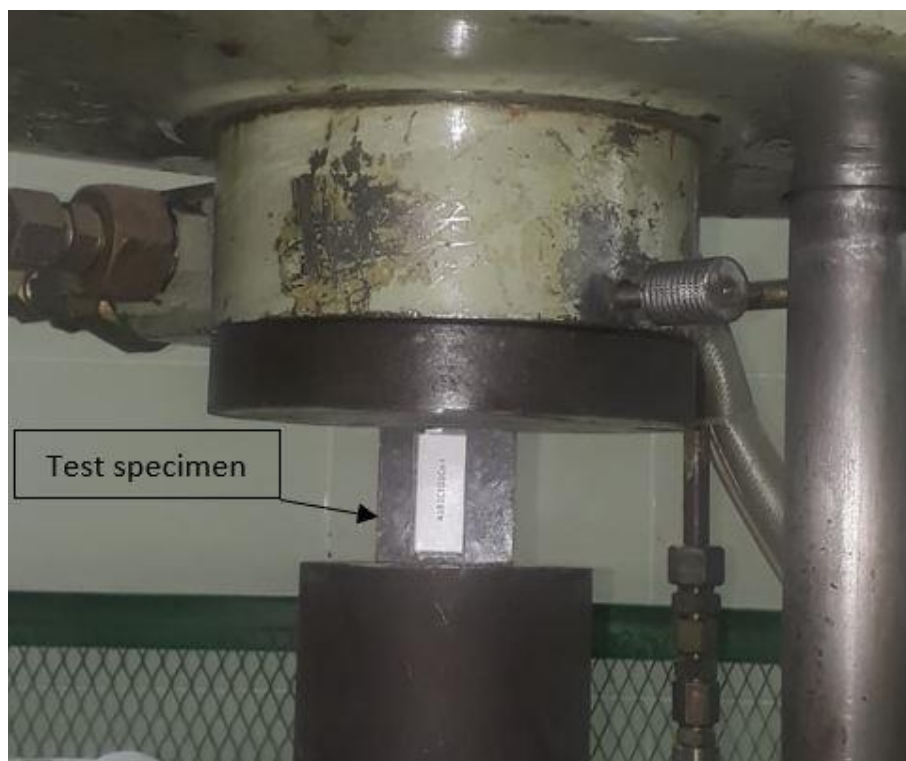


Fig. 4. Compressive test set-up

2.4 Flexural test

The tests were conducted according to ASTM-C580 Method B [24] and a universal testing machine M/C in Force and Material Metrology Laboratory, National Institute of Standards (NIS), Ministry of Higher Education and Scientific Research, Haram - Giza – Egypt. Testing machine was used to determine the flexural strength of the polymer composite of epoxy granite composite in the shape of a molded beam with rectangular cross-section area as shown in Fig. 5.

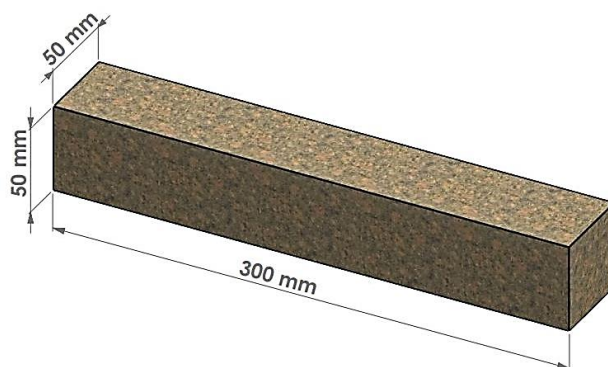


Fig. 5. Flexural strength test specimen

Flexural strength was applied using a rectangular cross-section bar of epoxy granite composite using the three-point bending method. The radius of the Loading nose is 6.35 mm as shown in Fig.6.



Fig. 6. Flexural test set-up

A crosshead speed of the universal testing machine is determined by using the following formula to achieve a strain rate (0.01 ± 0.001) per minute at the bottom and top of the testing beams [24].

$$\text{Speed} = \frac{0.00167 \times L^2}{d} \quad (4)$$

Where: Speed is the cross speed of the head (mm/min), L is the span in (mm), d = depth of tested granite epoxy beam in (mm). The used crosshead speed was 2.15 mm/min.

Epoxy granite specimens with the dimension of (50 ± 3) mm square section by (300) mm length was prepared according to ASTM-C580 /Method (B). The flexural strength and young modulus are calculated by using the following formula.[24], [18].

$$S = \frac{3FL}{2bd^2} \quad (5)$$

$$E = \frac{L^3F}{4bd^3\delta} \quad (6)$$

Where: S = stress in the specimen at midspan, psi (MPa), F = the maximum load at or before the moment of crack or break. (N), L = span, in. (mm), b = width of beam tested, in. (mm), d = depth of beam tested, in. (mm). and δ is maximum beam deflection. Three samples of granite epoxy composite were tested, and the average results values were recorded.

3. Results and Discussions

The results of the compressive strength and the flexural strength of the produce epoxy granite composite specimens with different percentage ratios of the epoxy are shown in Table 4. Compressive strength values and flexural strength for each granite epoxy specimen are checked to be sure that no specimen value differs from the observed mean value by more than 15 % [23]. The mean values observed of the compressive strength were 72.15 MPa for granite to the epoxy ratio of (80:20) % wt and 61.33MPa for granite to the epoxy ratio of (85:15) % wt, the mean values observed of the flexural strength were 19.79MPa for granite to epoxy ratio of (80:20) % wt. and 21.18MPa for granite to epoxy ratio of (85:15) % wt. It found that granite granule size provides greater ductility and the use of epoxy resin with strong adhesive properties ensures high strength and decreased deformation due to creep [25].

Table 4. Results of compressive and flexural strength results of specimens and Standard deviation.

Granite to epoxy ratio	Sample NO.	Compressive strength	Flexural strength
85:15 %	1	59	21.69
	2	62	21.40
	3	63	20.46
80:20 %	1	70.98	20.5
	2	71.98	20.45
	3	73.5	18.41

Table 5. compressive, flexural strength and Flexural modulus.

Epoxy ratio	Compressive strength	Flexural strength	Flexural modulus (GPa)
15%	61.33	21.18	2.873
20%	72.15	19.79	2.121

Compressive stress versus strain curves of an epoxy granite composite with granite to epoxy ratio of 85:15% wt and 80:20% wt been presented in Fig.5. The maximum compressive strength was observed for composition with 20:80 %wt. granite epoxy and the observed value was 72.15 MPa. It was found that increases in the epoxy ratio in the epoxy granite composite increased the compressive strength as shown in Fig.7.

From Fig.7 and Fig.8, it is observed that in specimen with 15% epoxy the amount of epoxy is little, but it just bonds the particles each other, therefore, the most load carried by granite, at this time the strength decrease while lack of bonding between particles increases brittleness increase and reduced the ductility as the material cannot withstand the load for long times. The epoxy resin in the specimen with 20% epoxy has a larger amount, therefore it an intersection between particles, therefore, it takes high part of the total load with the granite aggregates, hence the strength increased while brittleness increases and reduced the ductility as the material can withstand the load for long times.

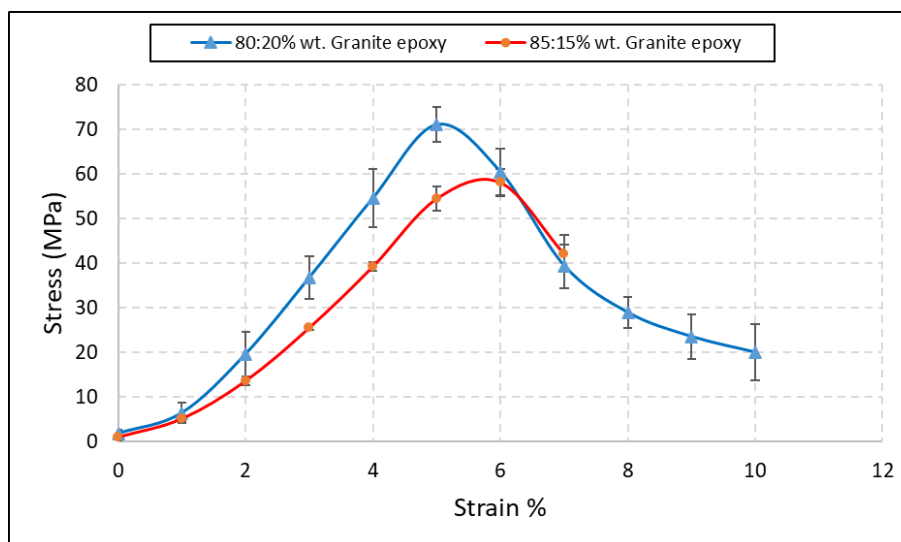


Fig. 7. Epoxy granite Stress-Strain curve.

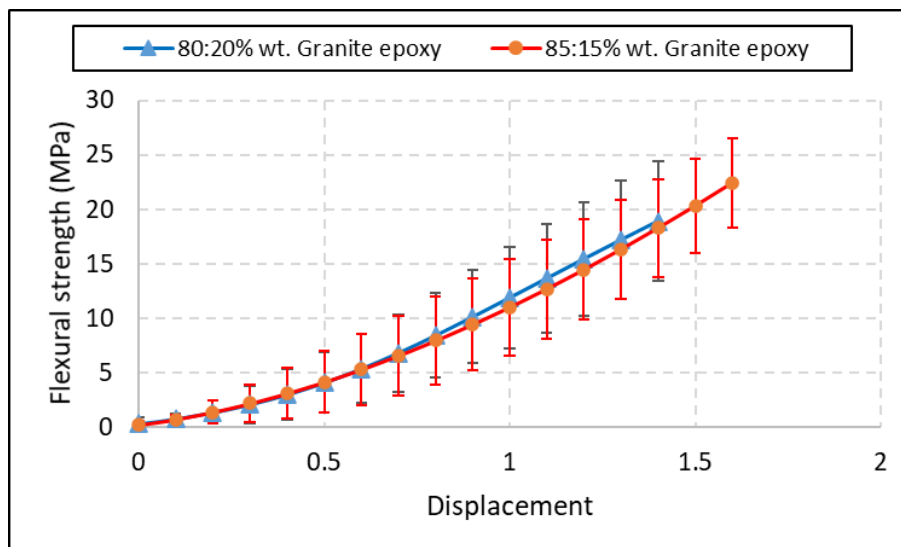


Fig. 8. flexural Stress-Displacement curve at granite to epoxy ratio of (85:15) % wt. and (80:20) % wt.

Samples with 15 % and 20% in weight of epoxy presented some areas with porosity as shown in Fig.9 and Fig 10. This porosity may be associated with the fabrication process as they have properties rounded format., this porosity may explain the reduction in compressive and flexural strength of samples. An attempt to increase the compressive and flexural strength shall deal with the reduction of porosity, which could be decreased using vacuum chamber. Failure mode in in compression. The failure occurs in the multiple fracture mode, epoxy granite specimen disintegrates along many planes in random directions as shown in Fig.9.

Failure mode in in bending. Brittle fracture modes illustrated in Fig.10. Focus. A dominant crack gradually initiates from the tension face and propagates upward to the load application point. The load–displacement curve of the epoxy granite test exhibits a linearly increasing portion up to the peak followed by a gradual post-failure portion accompanied by a relatively large load point displacement. The upper face of the beam subjected to compression force while the lower face subjected to tension force, fracture occurred in the middle third of the tension face.

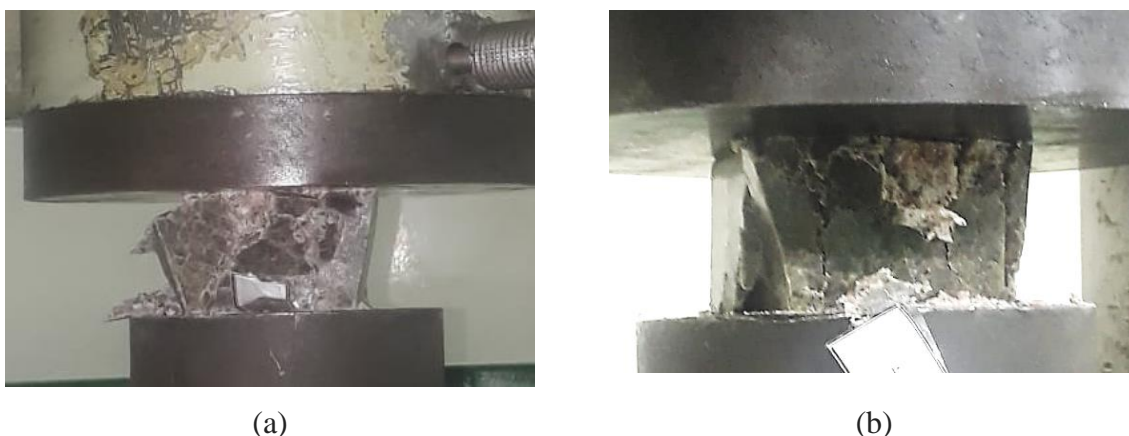


Fig. 9. Fracture at compressive test, at (a) 20% wt. epoxy and (b) 15% wt. epoxy.

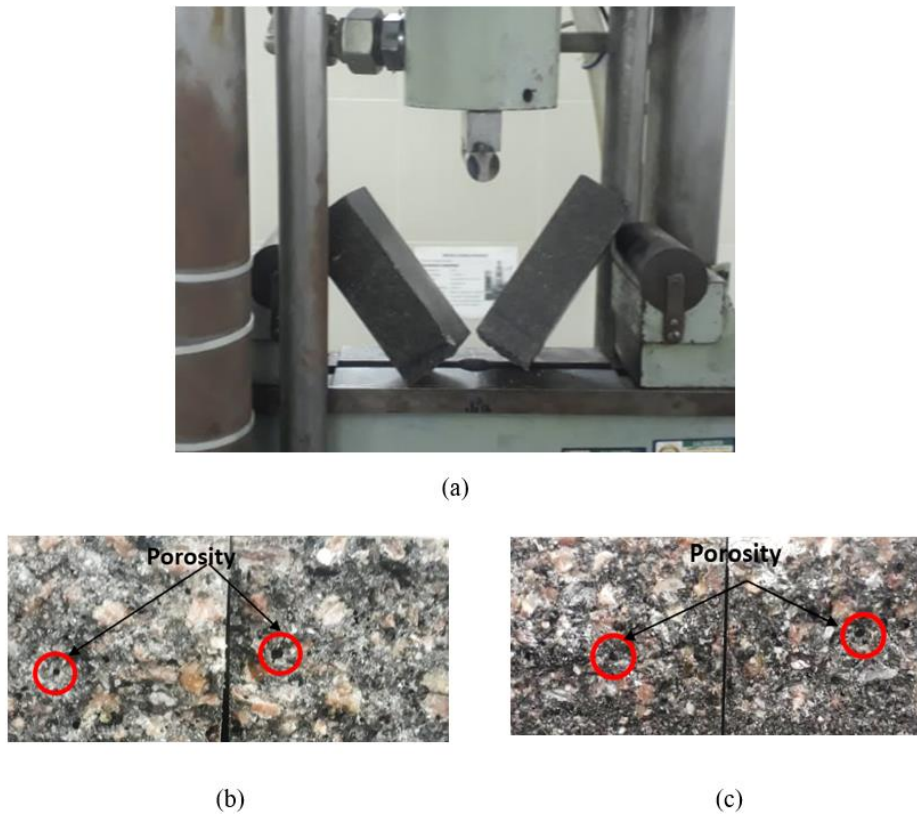


Fig. 10. (a) Failure under three-point single edge notch bending of particle size, (b) 15% wt. epoxy and (c) 20% wt. epoxy.

The variation and the stander error in the values of compressive strength and the flexural strength with the granite to the epoxy ratio of (85:15) and (80:20) % wt are represented graphically as shown in Fig.11. It was observed that the epoxy granite composite mix ratio proved at two different optimum levels, 80:20 for compressive strength and 85:15 for flexural strength. Epoxy granite composite with 20% in weight epoxy has superior properties to epoxy granite composite with 15% in weight epoxy.

The variation of the mechanical properties such as compressive and flexural strength of the composite material cement concrete, polyester concrete, and natural granite [25] [26] [15] with the epoxy granite composite is represented graphically as shown in Fig.12. and Fig.13. It was found that cement concrete seems to have inferior strength while both the polyester concrete and epoxy granite composite have considerably superior properties than the cement concrete. Epoxy granite composite has many superior properties than the polyester concrete. The properties of epoxy granite are superior in comparison to natural granite, making it clear that there was a strong interaction between the particles and the matrix and indicating that the low occurrence of pores in epoxy granite provided material with enhanced mechanical properties.

The average density (ρ) of the two composites of epoxy granite calculated according to the following formula,

$$\rho = \frac{m}{v} \quad (5)$$

Where: m is the mass of the epoxy granite specimen (Kg), v is the volume of the specimens (m^3).

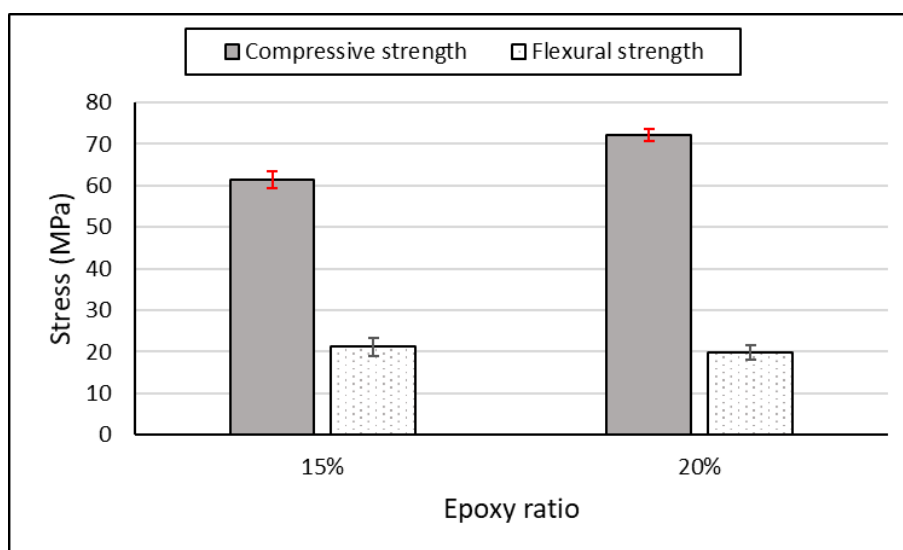


Fig. 11. variation in compressive strength and flexural strength with epoxy granite ratio

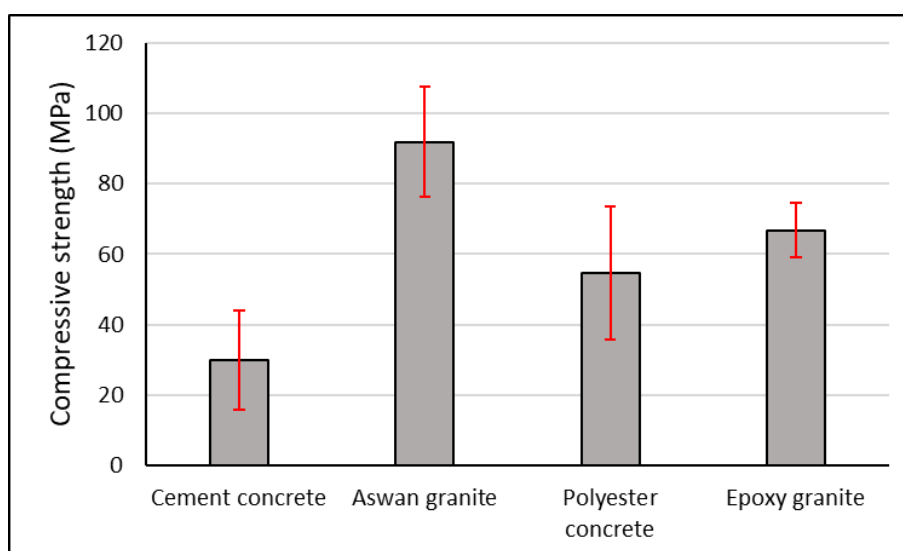


Fig. 12. Variation in compressive strength

The results indicate that the average density of the epoxy granite composite with granite to epoxy ratio of (80:20) % wt. was less than the density of epoxy granite composite with granite to epoxy ratio of (85:15) % wt. It observed that density of epoxy granite composite decreases with the increase the epoxy the epoxy percentage. The density of the epoxy granite composite with granite to epoxy ratio of (85:15) % wt. was 2079.9 kg/m³ while it was 1899.9 kg/m³ for (80:20) % wt. Epoxy granite composite is less dense than both natural granite and cast iron, the density of the natural granite was 2610 kg/m³ [14] and the density of cast iron was 7150 kg/m³ [15] as shown in Fig.14. due to the presence of the polymer material in its composition, which is considered as lighter material.

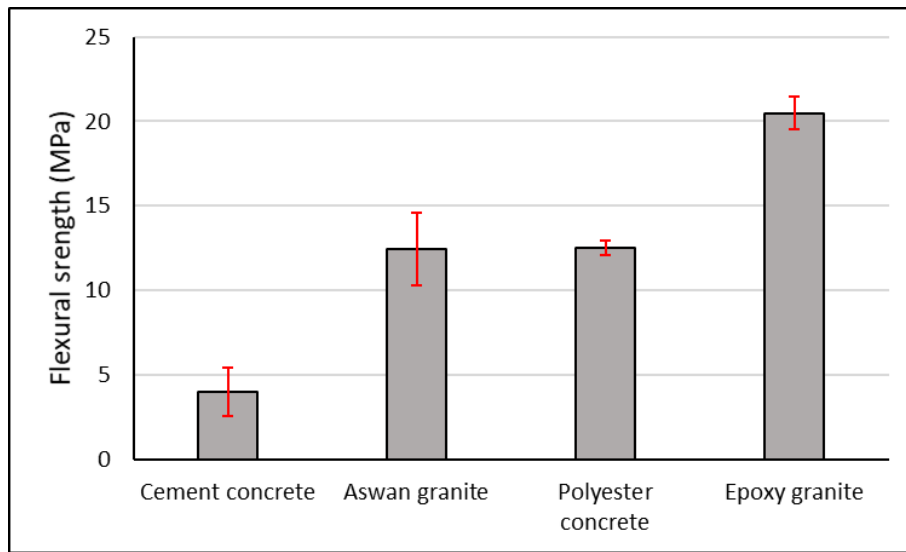


Fig. 13. Variation in flexural strength

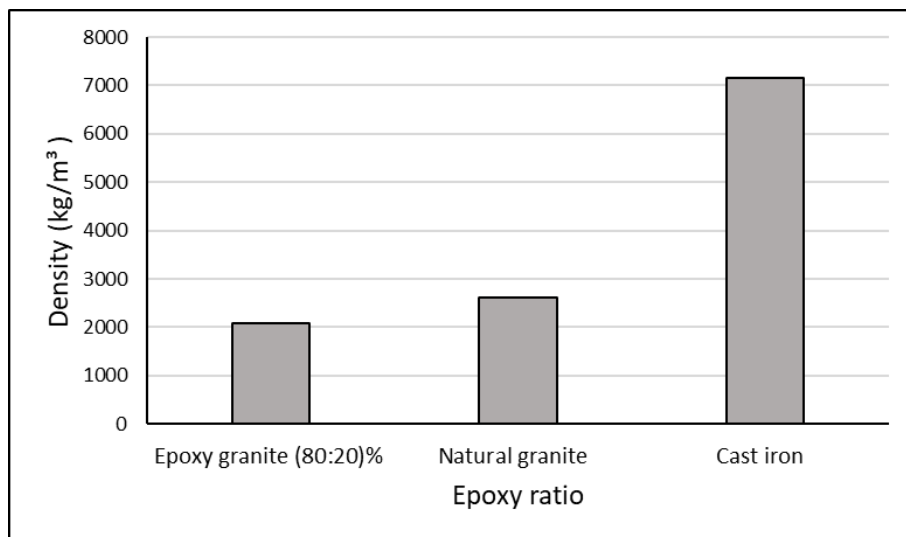


Fig. 14. Variation in density

4. Conclusions

Experimental study on mechanical properties of the Egyptian Granite particle filled epoxy resin composite is presented in this study. The influence of epoxy resin content between 15 and 20% in weight with the granite particles rate of 50% fine ,25% Middle and 25% coarse on compressive and flexural strength of the epoxy granite composite was investigated. The results showed that the compressive strength of epoxy granite composite induced with the highest value at 20%wt. epoxy ratio. The average values of the compressive strength of the epoxy granite composite were 64.33 and 72.15 MPa for 15%wt. and 20%wt. epoxy, respectively. The flexural strength of the epoxy granite induced with the highest value at 15%wt. epoxy. The value of average flexural strength and flexural young's modulus of epoxy granite composite was 21.18 MPa and 2.873 GPa for 15% epoxy and was 19.79 MPa and 2.121 GPa for 20%wt. epoxy. The flexural strength results showed superior magnitude with respect to cement concrete (5 MPa), polyester concrete (12.2 MPa), and natural granite (13.9 MPa). The compressive

strength results show superior magnitude with respect to cement concrete (40 MPa) and polyester (68 MPa), but it was reduced when compared to natural granite (102.9 MPa). Density of epoxy granite is less than the natural granite and approximately three times lower than cast iron. These results indicate that the epoxy granite composite produced with Egyptian granite residue and local epoxy resin can render the Egyptian granite waste as valuable, potentially profitable materials, Relevance for producing high precision Machine tools and will reduce pollution environmental.

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دراسة عملية على مقاومة الانضغاط وجساءة الانجلاء للمادة المركبة من الايبوكسي جرانيت للتطبيقات الصناعية

الملخص العربي:

في مصر، يتم إنتاج كميات كبيرة من نفايات الجرانيت سنويًا أثناء عمليات استخراج صخور الجرانيت. تمثل هذه النفايات مصدرًا مفيدًا محتملاً للمواد لمجموعة متنوعة من التطبيقات مثل مادة الحشو في المادة المركب من الجرانيت الإيبوكسي. في هذا العمل، تمت دراسة مادة مركبة جديدة كبديل عن المواد التقليدية المستخدمة في اجزاء الماكينات، مثل الحديد الزهر، لإنتاج كفاءة أفضل بتكلفة أقل. المادة المركبة الجديدة مبنية على الجرانيت، وهو مادة طبيعية تتمتع بقوة ضغط استثنائية وخصائص التخميد مما يجعلها مثالية لهيكل الأدوات الآلية. تم إجراء دراسة تجريبية على مركب مصفوفة بوليمر، تم تطويره باستخدام جسيم جرانيت كمادة مقواة مرتبطة بمصفوفة بوليمر إيبوكسي. تهدف هذه الدراسة إلى التعرف على الخواص الميكانيكية لمركب الإيبوكسي الجرانيت باستخدام الإيبوكسي المحلي (kemapoxy 150) ومخلفات الجرانيت في المحاجر المصرية وإعادة استخدام مخلفات الجرانيت لإنتاج مركب الإيبوكسي الجرانيت ذي الطبيعة الصديقة للبيئة. كان متغير المعالجة الذي تم فحصه هو نسبة الإيبوكسي المتواجده في تكوين مركب الايبوكسي جرانيت، وتم إجراء التوصيف الميكانيكي عن طريق اختبارات الانضغاط والانحناء وفقاً لمعيار ASTM باستخدام آلة الاختبار الشاملة. تم شراء جرانيت أسوان الأحمر المتوفر تجارياً وسحقه ونخله إلى ثلاثة أحجام تتراوح من ٠,١٥٠ إلى ٨ مم على التوالي. تم استخدام نسب إيبوكسي ٨٥:٢٠، ٨٠:٢٠، ٥٠:٢٥:٢٥ على التوالي لإعداد العينات. مع حجم حبيبات الجرانيت التي تتراوح بين (٠,١٥٠-٨) مم. أظهرت النتائج أن مركب الإيبوكسي الجرانيت بنسبة ٨٠: ٢٠٪ وزن. تسبب في أعلى مقاومة ضغط (٧٢,١٥) ميغا باسكال) بينما المركب بنسبة ٨٥: ١٥٪ وزن. أحدثت أعلى قوة انثناء (٢٠,١) ميغا باسكال). يُظهر مركب الجرانيت الإيبوكسي نتائج متفوقة فيما يتعلق بالخرسانة الأسمنتية وخرسانة البوليستر والجرانيت الطبيعي. تشير نتائجنا إلى أن مركب الجرانيت الإيبوكسي بنسبة ٨٠: ٢٠٪ بالوزن. مع الخصائص الميكانيكية الجيدة قد يكون لها إمكانات عالية في تطبيق أساس الماكينة كمواد غير مكلفة.