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RESEARCH ARTICLE - ENGINEERING

Mechanical Behaviour of Polymer Matrix Composite Reinforced by Silicon Carbide Particles

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Abstract

In various fields, Polymer-based composites are used extensively instead of traditional materials. The hand lay-up technology has been employed to prepare the composites of Silicon carbide particles-epoxy. Mechanical properties; shore D hardness, Flexural strength, tensile strength and impact strength were measured for all specimens. The present work has also studied the impact of different weight percentages (including 3, 6, 9, 12, 15 and 18) wt.% of SiC solid powder on the mechanical properties of fabricated samples with two average particle sizes of 75 and 105 µm. SiC particles were utilized as reinforcement with the epoxy with hardener according to the mixing of (3:1) ratio. The experimental results found that hardness, flexural strength and impact strength can be increased by increasing the weight percentage of Silicon carbide, while tensile strength is decreased with an increased weight fraction of silicon carbide. At the same time, these properties were enhanced when the particles of SiC have 75 µm more than at 105 µm.

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Keywords: Epoxy; Silicon Carbide; Composites; Impact Strength; Tensile Strength.

1. Introduction

Ceramic-matrix composites (CMCs) are composed or a mixture of two or more materials, which differ in chemical composition and physical properties. Ceramic reinforcement can be distinguished as oxide and non-oxi materials necessary because it has high mechanical resistance and improved mechanical properties such as impact strength, high specific stiffness, hardness, specific strength, low thermal expansion, good fatigue resistance and stability for manufacturing complex-shaped components. Composites commonly include matrices- reinforced with particles, dispersions or fibers [1, 2].

It is well known that epoxy can be considered the most useful and important polymer among different types of thermosetting polymers. This could be for various reasons such as lower thermal conductivity, higher corrosion, chemical resistance, and better mechanical properties. In addition to that, epoxy can be employed in various applications; composite matrices, high-performance adhesives, and coating.

The properties of composite exhibits can be easily enhanced by the particulate filler that is dispersed. In other words, it became possible to achieve such applications (Polymer composites fabricated) that have low eight materials and high strength. There are several advantages such as high thermal conductivity, excellent hardness and outstanding strength make it possible to use Silicon carbide (SiC) as a reinforcement in polymer composites in addition to enhancing thermo-physical properties [3, 4].

Moreover, the usage of Silicon carbide (SiC) as ceramic reinforcing material has received much attention by researchers for its structural applications compared with the typical materials. This attention is could be due to several other properties such as higher electrical insulation, inexpensive, easy processing, and a higher ratio of strength-to-weight and transferring load capability [5]. Recently, polymer composites can be possibly reinforced by nonmetals whereas the SiC particles are potential reinforcing materials for various composites. The incorporation of ceramic particles such as silica, alumina, tungsten carbide and silicon carbide as fillers can develop mechanical characteristics and tribological behaviour of epoxy resin matrix [6, 7].

On the other hand, inorganic fillers are used with the most of produced composite systems. Chanshetti et al. [8] assessed the behavior of composite wear resistance and hardness by using tungsten carbide and titanium oxide as reinforcing fillers in an epoxy matrix. As per their results, the wear rate has been reduced compared with epoxy resin which reflects the positive effect of the applied technology.

The morphological and mechanical properties have been examined with the presence of Al and SiC hybridization by Shohel Ranaet al. [9] in hybrid epoxy composites. Results revealed that increasing the Al and SiC loading led to an increase in the hardness, flexural modulus, young's modulus and impact strength whereas reducing the flexural and tensile strength.

Nomenclature & Symbols			
CMCs	Ceramic-Matrix Composites	TGA	Thermogravimetric Analysis
DMA	Dynamic Mechanical Analysis	SEM	Scanning Electron Microscope
XRD	X-Ray Diffraction	σ	Ultimate Tensile Strength (N/m^2)
F.S	Flexural Strength (MPa)	P	Applied Load (N)
L	Support Distance (mm)	d	Depth of Sample (mm)
b	Width of Sample (mm)	UC	Impact Energy (J)
I.S	Impact Strength (kJ/m^2)	A	Cross-Sectional Area (m^2)

Aleksandra Jeli´c al. were investigated the mechanical properties of magnesium silicate, dicalcium silicate, tricalcium silicate, Wollastonite and silicate nanofillers with epoxy resin which synthesized by using four ways and incorporating. Four methods were used Scanning electron microscopy (SEM), Fourier-transformation infrared (FTIR) spectroscopy, transmission electron microscopy (TEM) and X-ray diffraction (XRD). This study was founded the addition of 3% dicalcium silicate, magnesium silicate, tricalcium silicate, and wollastonite increased tensile strength by 31.51%, 29.01%, 27.49%, and 23.47%, respectively [10]. This study is concerned with the evaluation of mechanical properties such as hardness, tensile strength, impact strength and flexural strength for different weight ratios and size particles of SiC particulate and epoxy composite.

The flexural modulus ($\mathrm{F.S}$) was calculated by this equation (1) [11, 12]:

$$\mathrm{F.S} = \frac{3\mathrm{PL}}{2\mathrm{bd}^2} \tag{1}$$

In the above relation, the $\mathrm{F.S}$ represents Flexural strength (Mpa) whereas the P is the applied Load (N). However, the rest parameters are L refers to Support distance (mm), b and d are sample width and sample depth respectively.

Impact strength depends on the initial kinetic energy absorbed by the hammer and the resistance of epoxy-ceramic composites to external stresses applied to components of the composite material. By this equation, the impact strength values are calculated [13].

$$\mathrm{I.S} = \frac{\mathrm{UC}}{\mathrm{A}} \tag{2}$$

In the above relation, $\mathrm{I.S}$ represents the material Impact strength (kj/m^2) whereas UC and A are impact energy (j), and cross-sectional area (m^2) respectively.

The Flexural Strength tests were achieved by the three-point bending method. To evaluate the tensile strength, we used this equation.

$$\text{Tensile strength} = \frac{\text{Force}_{\text{Max}}}{\text{Area}} \tag{3}$$

2. Experimental

In the current work, the hardener used is Meta phenylene Diamine (MPDA) which is yellowish colour l and a light liquid mix with Epoxy resin type Conbextra EP10. After mixing these two materials, it was then converted into solid.

The Silicon carbide powder was ground by a ball mill to receive (75 and105 µm) average size after the sieving process.

The composites were fabricated by a mechanical mixer for 30 minutes. Firstly, a homogeneous mixture was obtained by adding (3, 6, 9, 12, 15and 18) wt.% SiC powder at two average particle sizes of 75 and 105 µm. SiC particles to the epoxy with hardener were used according to the mixing of (3:1) ratio.

The moulds were made from steel plates for the fabrication epoxy-Silicon carbide powder composites. The mixture was poured into a mould covered on the inner surface with special paper to prevent the specimens adhere to the mould.

After 24 hr., the solidification process is completed for all moulds. The curing is done in an electric oven at 50 °C for 6 hours. The casts are released from the moulds and softened. Casts were cut into specimens with desired dimensions for each test and according to the standard dimensions. Fig. 1 shows the samples and standard dimensions of samples for impact test based on the ASTM standard (ISO 179), flexural strength test ASTM standard D-790, The hardness of composites was tested using Durometer (shore-D) as per ASTM-D 2240 and tensile strength test ASTM (D 638) [14-17].

3. Results and Discussion

The mechanical properties of polymer–particles depend on the incorporation of the particles and matrix, also the chemical interface bonding between the particles and matrix.

Silicon carbide is commonly extensively used as abrasives in ceramic abrasives, reinforcement in composites, resin or diamond polishing wheels. This refers to its excellent properties like high hardness,

Silicon carbide powder is dispersed in the Epoxy resin so that to increase dense and void less structure to gain a good hardness, at the same time the volume of powder and the percentage of SiC powder improve the hardness of the composite [18]. Fig. 2 shows effect the weight fraction and particles size of silicon carbide powder which has a good abrasion on hardness.

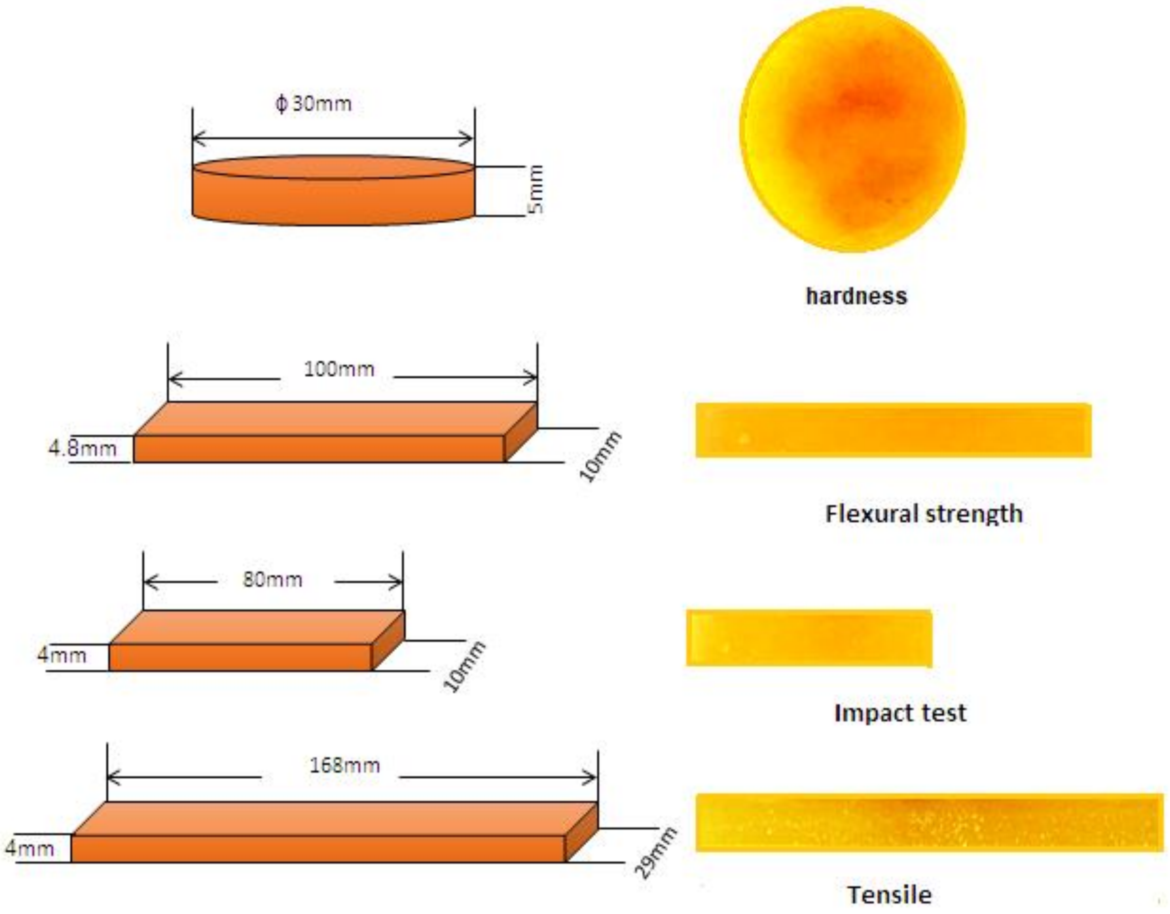

Fig. 1. The schematics and cast specimens

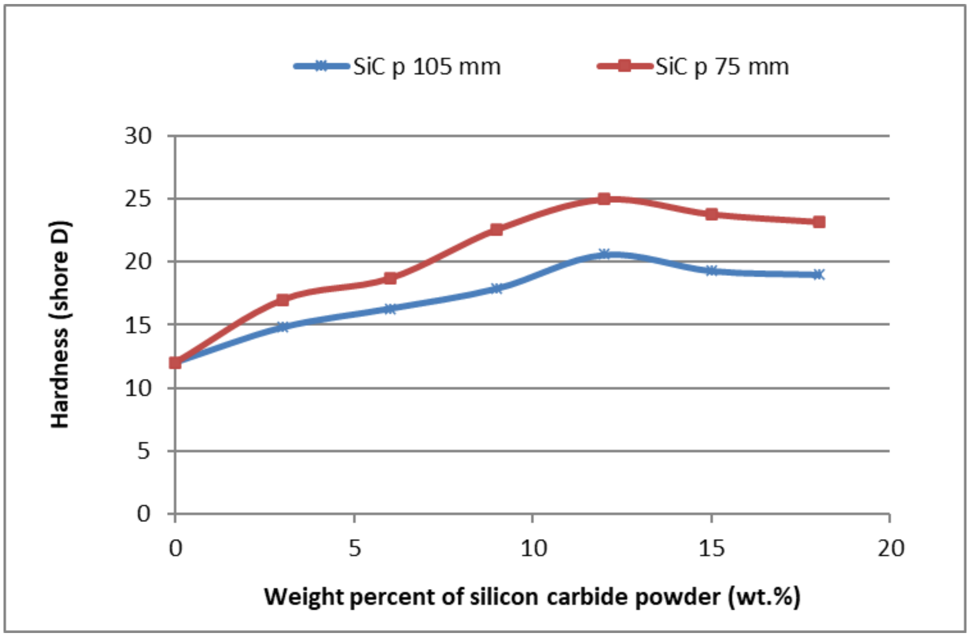

Fig. 2. Hardness no. of epoxy-silicon carbide powder composite in difference weight fraction

Hardness is a physical property which s is generally considered resistant to penetration. The harder material is resistant to penetration. Many factors influence the hardness of composites such as grain size, strain hardening, distribution of reinforcement etc.

The hardness of the considered composite is presented in Fig. 2 with different weight ratios of epoxy-silicon carbide powder. It can be seen that increasing the SiC weight fraction led to an increase in the hardness gradually with two considered particle sizes reaching the maximum level (25 shore D) with 12% of weight fraction at 75µm then started to decrease (23.2 shore D) with increasing the weight fractions to 18 wt.%. But the values of hardness at 105 μm (20.6 shore D) at 12 wt.% to begun decreases to reach (19 shore D) at 18 wt.%. Hardness was increased at (3, 6, 9, 12) wt. % of SiC powder but at 15 and 18 wt.% was decreased, this refers to agglomeration and deposit of the SiC powder in epoxy. This figure illustrated the hardness enhancement when the volume of SiC particles 75 μm is more than 105μm. This is could be due to a gradual increase in the ratio of resistance strength of polymer to plastic deformation. This behaviour acted in agreement with the results proposed by Jabbar Hussein [19].

Several factors can affect the result of sample hardness in the shore D hardness test with the presence of epoxy-SiC powder composites includes; matrix characterization, particle nature, and distribution between the epoxy resin and SiC particles. Due to the ability of powder loading, the SiC particles have a larger hardness than that of epoxy material. The sufficient dispersion of hard silicon carbide particles in epoxy resin can improved the hardness in addition to the presence of the particles on the surface of the epoxy resin. Also, the higher values of hardness were also associated with lower porosity.

Relation between Flexural strength and weight fraction of silicon carbide powder appears in Fig. 3.

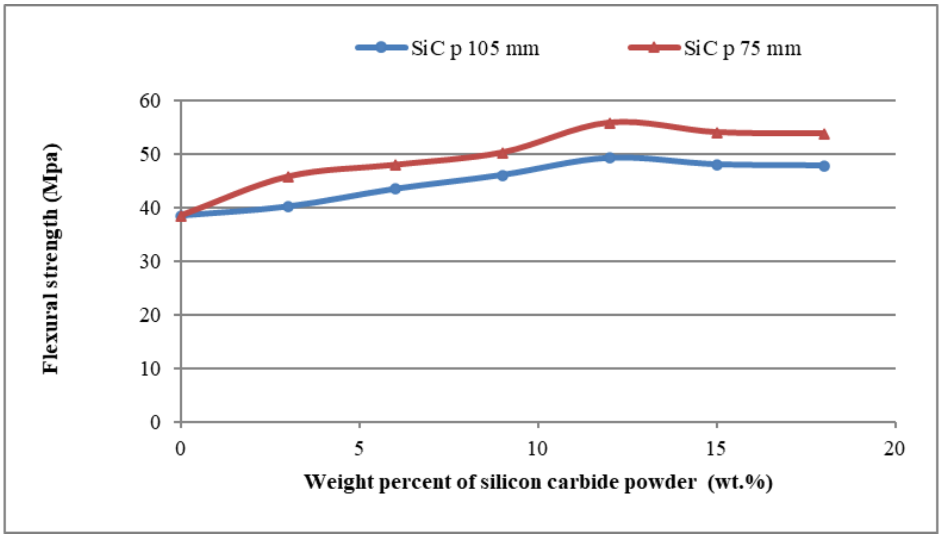

Fig. 3. Flexural strength of epoxy-silicon carbide powder composite in difference weight fraction

In Fig. 3, the flexural strength of SiC powder–epoxy composite increases from 38.5 MPa to 55.9 MPa with the increased content of silicon carbide from 0 to 12 wt, % at (75μm) particle sizes and increase from 38.5 MPa to 49.3 MPa at (105 μm). When increasing the quality of the interface between SiC powders – the matrix-assisted transfer loads from one end to the other and increases flexural strength. Silicon carbide makes efficient the stiffness of composites. This enhancement can be attributed to the stiff nature of silicon powder. These observations were studied by many researchers [20].

It is deduced that by increasing the weight fractions of silicon carbide powder from 3% to 12% with a step of 3%, there is a gradual increase in flexural strength. This is might be owing to the bonding nature and strengthening mechanism as well as the interface between SiC particles and epoxy. Flexural strength decreases After 12 wt. % because the increase in the amount of SiC powder contributed to the formation of the clusters and deposition of these clusters.

From Fig. 3, it can also be seen that the degree of plastic deformation reduces with increasing silicon carbide particle content.

The Fig. 4 shows the tensile strength for the specimens of epoxy-SiC particles composites with different weight fraction and volume fraction of reinforced materials.

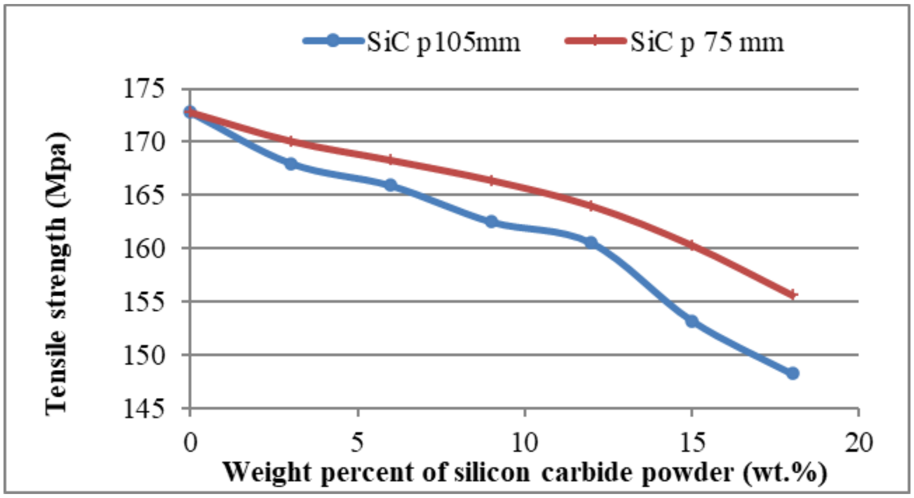

Fig. 4. Effect of powder loading on the Tensile strength of considered composite

Tensile strength was decreased with the addition of SiC powder to the epoxy matrix. It is also obtained that there is a reduction in the tensile strength of the considered composite with increasing reinforcement. The interface is the weakest area in a composite because the interfacial area increases. At the 105 µm of SiC particles, the tensile strength was decreased from 163 MPa at 3 wt.% to 148.2 MPa at 18 wt.% of SiC particles. At the same time, the tensile strength decreased from 170.1MPa at 3 wt.% of SiC particles and 75 µm to 155.6 MPa at 18wt.% in the same average size. An increase in the particle size of SiC particles leads to a decrease in the tensile strength because of the irregular distribution of silicon particles in epoxy resin.

Silicon carbide powder is stiffer than epoxy, therefore the load-carrying capacity of composites improves the interface between SiC particles content which leads to a decrease in tensile strength.

The Charpy test is one of the important impact tests by evaluating the ability of a material to resist dynamic loads. The distribution of additional energy in the composite materials depends on the strength of adhesion between the epoxy resin and the particles. That way preventing or reducing formation flaws in composite specimens.

Fig. 5 presents the influence of loading SiC powders on impact strength for epoxy composites. The impact strength is deduced to increase when adding silicon carbide powders at 75µm and 105µm in epoxy composites reaching the maximum value at the weight fraction (12%). This behavior indicates the adhesion of SiC particles with the epoxy resin is sufficient to increase and improve simultaneously the absorbed energy and reducer void spaces in composites [21]. After this weight fraction, the impact strength was depressed because the bonding strength between the silicon powder and epoxy was reduced. Also, a large amount of energy is focused on crack initiated in the SiC- epoxy interface.

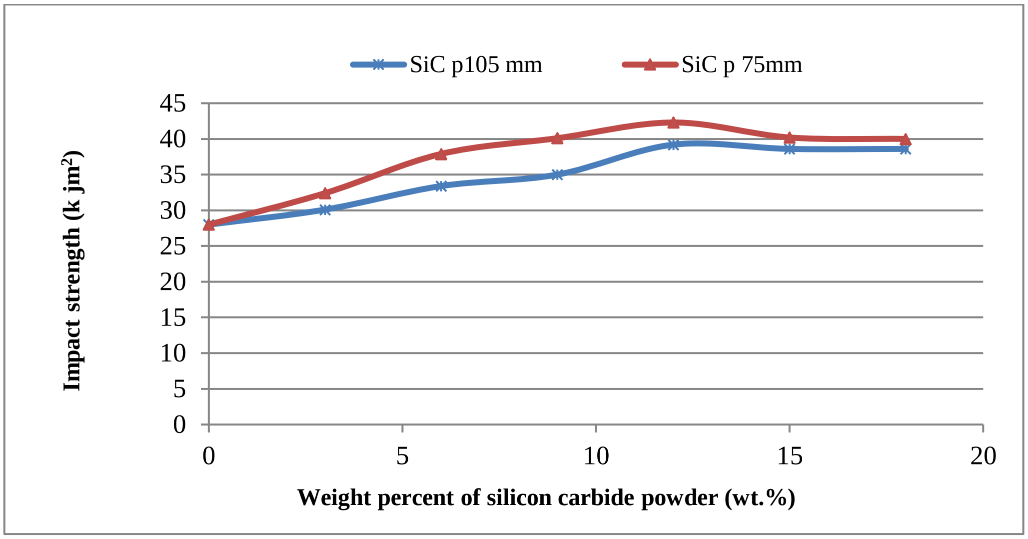

Fig. 5. Effect of powder loading on the impact strength of considered composite

The impact test shows a sufficient dispersed of silicon particles in epoxy resin inhibited the flaws and cracks. It was seen that the volume fraction of silicon carbide particles was a very important factor for impact strength. The lower volume fraction of SiC particles improved the impact strength [22]. It was seen that 12 wt. % and 75 µm of silicon carbide particles had the best impact strength values. The results exhibit that the smallest SiC particles led to good dispersion and improved impact strength values.

4. Conclusions

The current work can be concluded as follow:

- Shore D hardness gradually improved with added silicon carbide (3 to 12 wt. %) content to reach (25 and 20.6) shore D at two average size particles (75 and 105) µm respectively after these percentages, which began to reduce the hardness. The increase in shore D hardness is due to the hardness of silicon carbide particles on the epoxy matrix and good dispersion, especially at 75 µm.
- Values of the flexural strength for all specimens for two sizes (75 and 105) µm increases from (38.5 to 55.9) MPa and (38.5 to 49.3 MPa) respectively with added silicon carbide powder (3 to 12 wt. %) content. The results indicate the flexural strength was decreased slightly after 12 wt. % of SiC particles.
- The tensile strength of silicon carbide powder –epoxy matrix composites reduced up to (3-18) wt. % of reinforcement. At the 105 µm of SiC particles, the tensile strength was decreased from 163 MPa at 3 wt.% to 148.2 MPa at 18 wt.% of SiC particles. At the same time, the tensile strength decreased from 170.1MPa at 3 wt.% of SiC particles and 75 µm to 155.6 MPa at 18wt.% in the same average size.
- The impact strength of SiC particles -reinforced epoxy matrix composites were found to be increased with the increase in reinforcement (3 to 12 wt. %) in the epoxy matrix composites, beyond which it reduced.
- At size 75µm for SiC particles, the values of mechanical properties (hardness, flexural strength and impact strength) more than at 105 µm because the sufficient distribution of powder in epoxy resin.

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