MECHANICAL PROPERTIES AND RELIABILITY OF GLASS-ALUMINIUM COMPOSITE AS INSERT MOLD

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Abstract

Plastic injection mold made of tool steel is generally utilized for large lots production. Running for small lots of product is a new trend of demand, so that the mold would be relatively expensive and not competitive. The aim of the present work is to find an alternative material and process for low cost injection mold that suitable for small lots. For these reasons, aluminum-glass-acrylic particulate composite would be proposed as a material for manufacturing of low cost plastic injection mold. In this work, an insert mold as part of the injection molding was selected for the case study. Composite was examined to know its characteristics. The part with size of (80mm x 10mm x 10mm) and (30mm x30mm x30mm) made of particulate composite material was selected as specimen. Material of the specimen was aluminum powders (<297 µm), glass powders (<74 µm) and acrylic powders (<74 µm); the volume ratio is 1:1:1. Acrylic was used for binder when composite made by layer manufacturing method, using Selective Heater Melting (SHM) machine. The specimen was prepared into three steps: manufacturing of composite (green specimen) by SHM machine, heating green specimen to burn up the acrylic, and resin impregnation. There were 3 types of specimens: green specimen before heating at 700°C, green specimen after heating at 700°C, and green specimen after heating at 700°C that continued by resin impregnation. Tests was performed to investigate its bending strength, surface hardness, surface roughness, and dimensional error. The other composite (specimen) was insert mold, made by layer manufacturing method, using SHM machine. Case study was carried out by testing an insert mold to know the reliability of insert mold.

Bending strengths of green specimen, before and after heating at 700°C, were 2.07 and 8.23 MPa, respectively; and after resin impregnation was 17.15 MPa. Dimensional errors in the direction of X, Y, and Z-axis for green specimen of (30mm x 30mm x30mm) before heating at 700°C were 8.65, 2.7, and 3.8 mm, respectively; and after heating at 700°C were 7.90, 1.10 and 0.90 mm, respectively. Surface roughness of green specimen before and after heating at 700°C were 46.12 and 33.48 µm, respectively; and after resin impregnation was 12.17 µm. Surface hardness of specimen after resin impregnation was 14.199 BHN. The amount of plastic parts that could be produced by insert mold was 120 and 126 pieces. Although mechanical strength of this composite was lower than that of tool steel that used for common plastic injection mold, but this composite material was less expensive and suitable for small lots production.

Keywords: *Layer manufacturing, Selective Heater Melting (SHM) machine, green specimen, insert mold.*

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1. INTRODUCTION

Injection molds that are presently applied in industrial plastic, generally made by machining process, using materials such as carbon steel, alloy steel, shock-resisting steel, cold-work steel, mold steel, martensitic stainless steel, high-grade zinc alloys, tin-bismuth alloys [1], carburizing steel, maraging steel, maraging SS, high-speed steel, and beryllium-copper [1]. Bulk steel for injection mold generally has a tensile strength of 520 to 2070 MPa, yield strength of 360 to 1900 MPa, and hardness of 122 to 300 BHN [1]. The surface roughness of mold for general use or general purpose was 0.2 µm [2]. Another material for injection mold such as tin-bismuth alloys has a melting point of 138-170°C, tensile strength of 56 MPa and hardness of 20 BHN.

In term of fabrication method, mold could be made by several methods such as machining of bulk material, casting and layer manufacturing methods; and the mold could be tested its reliability by running the mold in the plastic injection machines for producing the products and counted the number of product till the mold wear. Machining of bulk steel for making mold was very common till present day. However, the shape and geometry of its cavity was limited to the symetric shape. Since it was only drilling or boring tool that available in this machining technology, therefore it was only straight cooling channel could be made. For another geometry like cylindric or irregular shape, conformal cooling channel could not be made. In casting method, Jetley and Low [3] fabricated a mold using tin-bismuth alloys. The products that were produced and met the criteria could reach 500 pieces. In layer manufacturing technology, mold can be made by arranging plate or sheet or sintering of powder, depending on the form of materials they will be used. Doehler [4] fabricated mold by arranging thin plates of carbon steel. In this method, the plates was stacked and machined to shape into mold. Fabrication method of part by arranging material in the form of plate or sheet later on it was known as Layered Object Manufacturing (LOM) method. In making mold by selective laser sintering metal powder, there were two methods depending on the material powder which called direct sintering and indirect sintering. In the direct sintering, sintering process was carried out directly to the metal powder. In this, sintering temperature was set up at a few degree below the melting temperature of the metal powders. Whilst in the indirect sintering, sintering temperature was set up at the melting temperature of the binder material. Thus, green part/green specimen would be produced and it needs further post processing such as infiltration to obtain better strength and density. The post processing can be performed by heating up the green part to burn the binder. Since the binder was out from the part, voids was then exist and in order to have a dense part, the part is infiltrated with another melted material. Several materials have been widely used for making this mold, namely polymer coated low-carbon steel powder with copper infiltrant that could produced 50,000 part pieces [5]; polymer coated steel powder with bronze infiltrant which could produced 200,000 pieces per year for 5 years life time [6]; and tool steel powder with cast iron infiltrant [7]. All those mold material based steel were dedicated for mass production or large lots product, it was high wear resistant and of course expensive. Thus, in the situation where small lots is needed, this mold would not be suitable and probably high operational cost. For these reasons, finding an alternative low cost material and fabrication method would be challenging. Material such as metal reinforced glass matrix composites with binder probably could be used, although it was not widely explored as a plastic injection mold material. Attention was paid to find composite composition and mechanical strength. It was few existing research could be found. Bernardo [8] found that the advantage of using thus composite was low sintering temperature of about 50°C above the dilatometric softening temperature and save energy. In addition to this, the sintering process does not require the rigorous atmosphere, because the sintering process can also occur in the normal air atmosphere. In the study, they used glass matrix composite including aluminium reinforced lead-silicate glass matrix composite. The lead-silicate glass waste was obtained from the waste of cathode ray tubes (CRTs) of PC's and TV's monitors. The size of the glass powder < 37 μm and the aluminum powder < 75 μm. A mixture of 80 vol% of glass powders and 20 vol% of aluminum powders was pressed at a uniaxial pressure of 350 bar (35 MPa) in a steel mold (rectangular cross-section, 50 mm x 34 mm) using a hydraulic press at room temperature (cold-pressing) to form a compact part. Subsequently, the compact was pressureless sintered at a temperature of 600°C for 5 hours. In the mechanical testing, they found that its bending strength of the specimen was 65.40 ± 9.32 MPa. Similar to this reseach was Montazerian et al. [9] They examined the partially stabilized zirconia (Y-PSZ) reinforced mica glass-ceramic composites with 5%, 10% and 15% weight ZrO_2. They used glass powders and Y-PSZ powders with particle size of 12.5 μm and 0.89 μm, respectively. The mixtured powders was pressed using uniaxial hydraulic press of 65 MPa into discs of 10 mm diameter and 4 mm thick. The process was conducted at room temperature and sintered without pressure at temperatures ranging from 1060 to 1170°C with holding time of 240 minutes. They found that the maximum bending strength of 132.47 ± 13.80 MPa occurred for the specimen with 15 wt. % ZrO_2. Another research was Rajesh, et al. [10]. They investigated the composite was made of alumina filler with average particle size of 5μm and matrix of G018-250 (lead-free aluminoborosilicate) and bismuth glass with particle size of 4 μm. A mixture of 50 wt.% Al_2O_3 and 50 wt. % glass was uniaxially pressed into pellets with diameter of 11 mm and height of 2 mm. Pellets were sintered at temperatures ranging from 600°C to 750°C with heating rate of 5°C/min in air atmosphere. While, Kim et al. [11] examined the composite made of 50% Al_2O_3 - 50% PBS glass (lead borosilicate glass). Samples in the form of disk with diameter of 15 mm were prepared by compacting the powder mixture at a pressure of 50 MPa and sinter at temperature of 600-950°C for 2 hours. The last similar research was done by Darmo et.al [12]. They developed composite of glass, aluminum, and acrylic powders with volume ratio of 3:2:1. Particle size of each powder was about <425 μm. Green specimens were made by filling a mixture of these materials into the mold with a size of 10mm x 10mm x90mm, heated in a furnace at a temperature of 250 °C for 1 hour. The green specimens then was further heated in a furnace at a temperature of 600°C, 650°C, and 700°C for 1 hour. Maximum bending strength their achieved was 40 kg/cm^2. At the same year, Darmo [13] carried out a similar study, but using a finer powder with different volume ratio. The particle size of aluminum powders was < 297 μm; glass and acrylic powders was < 74 μm, respectively; and the volume ratio of the composite was 1:1:1. Green specimen was made by heating the mixture at a temperature of 250°C, subsequently, heated at a temperature of 650°C, 700°C, 750°C, 800°C, and 850°C, and followed by a bending test. Maximum bending strength was 323.20 kg/cm^2 achieved by sample with heating at a temperature of 750°C. This bending strength, more over, was almost 8 times higher than that of using coarse powder. Continuing study of thus composite material using selective heater melting (SHM) for fabrication specimen, Darmo et.al [14] found that quality of bonding between the particles in the composite was strongly influenced by the volume ratio of the powder mixture and scanning speed of the heater with assuming that tip heater temperature was remain constant. Quality of the bonding observed included the strength of the bond and the shape of the specimens. The shape of the specimens must be maintained (not collapse), when green specimens are reheated at a temperature of 700°C. The results showed that a good bond between the particles was occurred if the heater scanning speed was 100 mm/min, and the volume ratio of the mixture of the aluminum, glass, and acrylic powders was 1:1:1. Naturally, aluminum is an active metal and reacts with oxygen from the air to form a thin hard layer of aluminum oxide (Al_2O_3) on the surface. Layer thickness of the oxide (alumina) at room temperature condition was 2-3 nm and approximately 1μm when heated up at 600°C [15]. Melting point of Al_2O_3 was approximately 1926°C, while pure aluminum was only 660°C [16][17][18][19]. Heating aluminum of which the size of particles was in micro-scale (μm), causing the formation of γ-Al_2O_3 scale, before reaching the melting point of the aluminum; whereas the liquid of the aluminum was remained inside the γ-Al_2O_3 shell. Further heating caused the formation of θ-Al_2O_3 scale, grew simultaneously with γ-Al_2O_3. The γ-Al_2O_3/θ-Al_2O_3 scales remained stable and protective at isothermal conditions, up to a temperature reach 800°C [20]. The oxide layer decreased the properties of sinterability of aluminum powders. Therefore, pressure should be performed on the aluminium powders up to 490 MPa which was carried out before carrying sintering process at a temperature of 640°C to gain better sinterability [21]. This pressure caused the plastic particles deformation and breakup the oxide layer. As a result, cold-weld occured at the areas of the oxide-free as a location of diffusion processes of atoms during sintering process [22]. Glass and aluminium are good combination material. Glass powder was able to bind aluminum powder due to chemical reaction at the interface between aluminum and glass particles [8]. The ability of glass to bond to aluminum at 700°C was also proven by Liu, et al. [23]. Their research was performed by mixing Pyrex 7740 glass (80.9 wt% SiO_2, 12.7 wt% B_2O_3, 2.3 wt% Al_2O_3, and 4.0 wt% Na_2O) and aluminum (purity: 99.997%) at temperatures of 350-450 °C that generated by DC electric field at a voltage of 400-700 V. Bonding between the glass and the aluminum occurred due to the diffusion bonding. Na^+ ions move away from the interface of glass-aluminum, whereas oxygen ions diffuse into that region, and react with the silicon (Si) to form Si-O bonding [23]. Alumina in the glass serves as intermediate oxides, enter into the silica network as tetrahedra AlO_4^{4-}, replacing some groups of SiO_4^{4-} [24].

In order to sinter at relatively low temperature, binder is required for manufacturing of composite green part. Yan, et al. [25] conducted a study on green parts made by using Indirect Selective Laser Sintering (SLS) process. In their study, the specimen was made of carbon steel powder as the main material and nylon-12 resin as a binder. Nylon-12 has a glass transition temperature of 181.1°C [26]. For the green specimen, bending strength was influenced by the nature of bonding of binder. The increase in bending strength was due to the increase of the laser energy density and vise versa. The decrease in bending strength was happened when the viscosity of the polymer as a binder was decreased, so that the binder was decomposed. Another binder like acrylic was introduced by Darmo, et al. [12] to fabricate composite of aluminum and glass powders. Acrylic serves as a binder of the mixed of glass and aluminum powders. Acrylic (polymethyl methacrylate, PMMA) has a melting temperature of 149°C [16]; aluminum was about 660°C [16]; glass was about 1400°C, and the glass transition temperature was about 530°C [27]. In the study, when aluminium particles were heated at a temperature of 700°C, the shape of aluminium particles was not change, and the surface of aluminum particles undergos strong oxidation to form alumina [28], but the particle of aluminum and the glass was bonded very well. Sure that many beneficial of employing layer manufacturing technique in fabricating a 3-dimensional object can have it. Not only its ability in building a complex geometry that machining process could not able to perform, but also a wide range of material types can be processed. Beyond those advantages, there is dimensional error still exist in x, y and z directions. But, mostly in z-direction which is biggest error and known as bonus-Z. So far, this dimensional error have been solved by giving size compensation and positioning the part orientation before running the process. However, pay attention of the research still in it. Yan, et.al [25] found that dimensional error of the selective laser sintered part (carbon steel and nylon-12 powders) was influenced by heat energy density and travel speed of the heater. The heat received by the composite material became higher if traveling speed was low, and vice versa [29]. Dimensional errors occurred to the green specimen in the direction of x, y, and z axis were 0.207, 0.199, and 0.587%, respectively. The dimensional errors occurred due to the loose powders that directly in contact with the sintered parts reached temperature above a caking sintering tempera-ture, causing the part grew larger. Following success of developing the composite of aluminum-glass with binder of acrylic and trial in making specimen using SHM in the previous research, then the present work would like to focus on manufacturing of an insert of plastic injection molding and testing of running production. SHM machine is a machine used for making 3D objects, by means of layer by layer method, using radiation heater of pencil type (use glow plug) as a heat source. The maximum temperature of the heater is about 500°C.

2. METHODS

2.1 Materials

Composite materials have been used in this work consists of aluminum powder (< 297 µm), glass powder (< 74 µm), and acrylic powder (< 74 µm). The powders have been characterized following the previous work by Scanning Electron Microscope (SEM), Energy Dispersive X-Ray Analysis (EDAX) and X-Ray Fluorescence (XRF). Glass powders have angular shape particles with composition of 70% SiO_2, 1.5% K_2O, 24.7% CaO, 0.43% TiO_2, 0.075%Cr_2O_3, 0.01% V_2O_5, 0.074% MnO, 1.8% Fe_2O_3, 0.959% NiO, CuO 0.12%, 0.014% ZnO, BaO 0.1%, and 0.1% Re_2O_7. Aluminum powders have flake shape particles with composition of 96.14% Al, 2.67% Mg, and 1.19% Si. While the acrylic powders have irregular shape particles with composition of 8.10% C, 34.78% O, 16.67% Na, Mg 0.79%, 0.96% Al, Si 15.73%, and 22.96% Ca.

2.2 Bending Test

Fig-1 shows the flowchart of manufacture of specimen and bending test.

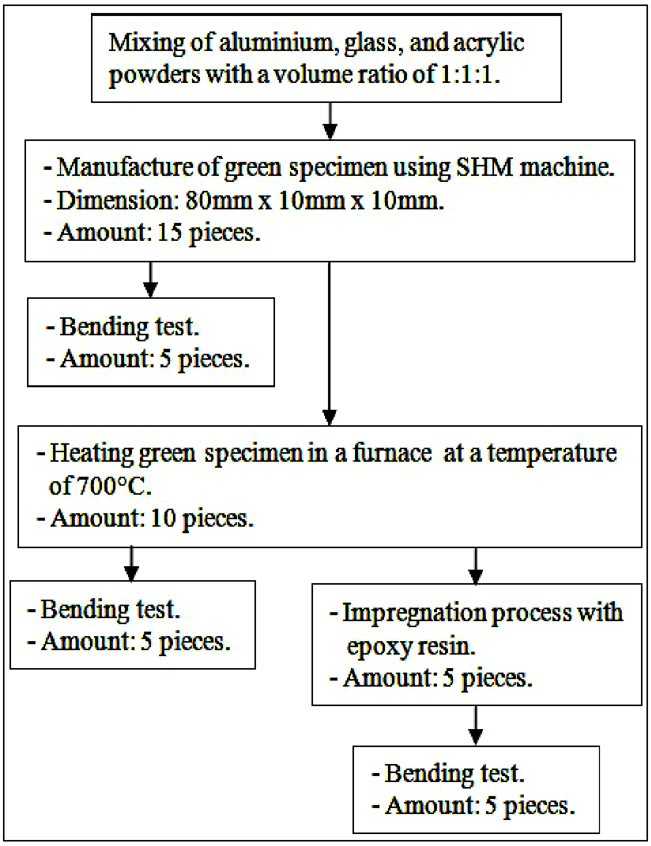


Fig-1 Flowchart of manufacture of specimen and bending test

The aluminum, glass and acrylic powders, mixed with a volume ratio of 1:1:1, using a rotary mixer for 3 hours, at 70 rpm. Selective Heater Melting (SHM) machine, was prepared and programmed, for the manufacture of green specimens with the size of (80mm x10mm x 10mm). The heater velocity, was designed at 100 mm/min; path length of actual movement of the heater of the Selective Heater Melting (SHM) machine was measured in the direction of X-axis and Y-axis. Actual length in Z-axis direction, i.e the distance of movement of build piston, measured in the vertical direction. Measurement was performed when the Heater Selective Melting (SHM) machine was being operated. Preparation of the specimens was done by making green specimens, made of the powder mixture, by means of layer by layer method, using Selective Heater Melting (SHM) machine. Fig-2 shows the SHM machine that used in this research.

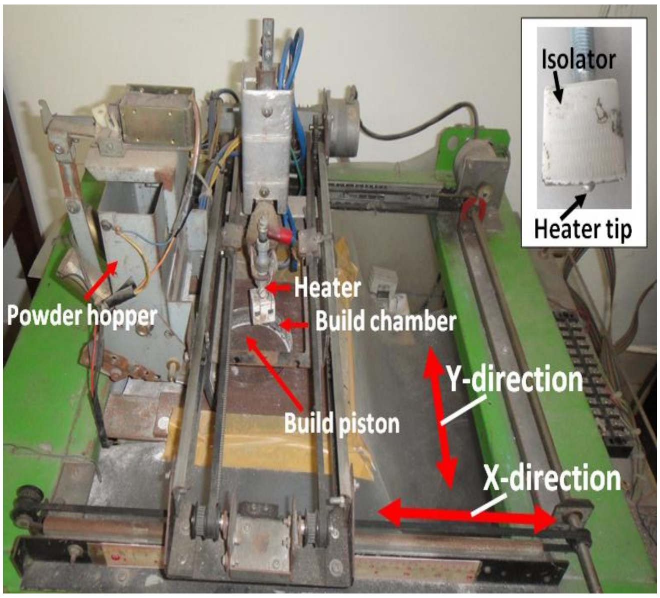


Fig-2 Selective Heater Melting (SHM) machine

Steps of manufacturing method of green specimen (composite) made by using SHM machine is as shown in Fig-3 to Fig-6. Step 1: powders are fed into the build chamber, from hopper (Fig-3). Step 2: powder sweeper plate sweeps/flatten the pile of the powders (Fig-4). Step 3: the heater move down, approached the surface of the powder, then heating the powders; one layer of composite (green specimen) is formed (Fig-5). Step 4: the heater moves up and build piston moves down to the distance of 1 mm (Fig-6). Step 5: powders were fed into the build chamber, from hopper (Fig-7). The next step is the same as step 1 and so on. The process is repeating until the amount of the layers is appropriate with the design.

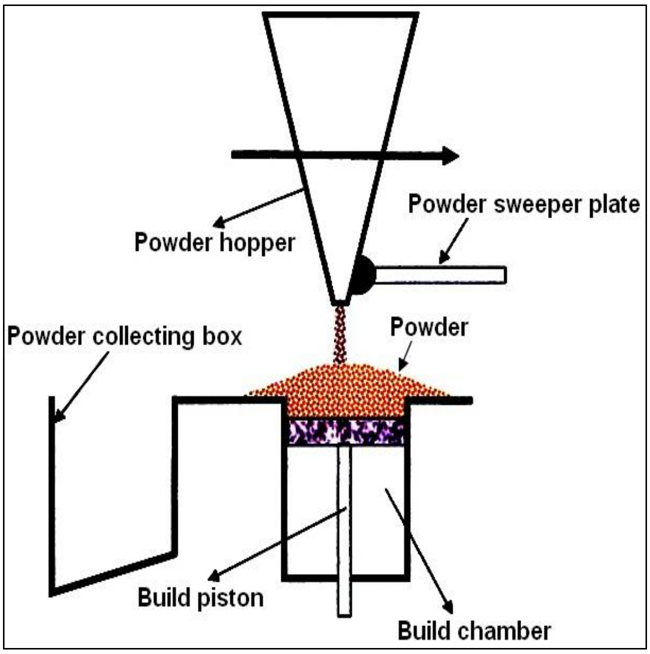


Fig-3 Step 1 of manufacturing process of green specimen; powders are fed into the build chamber, from hopper

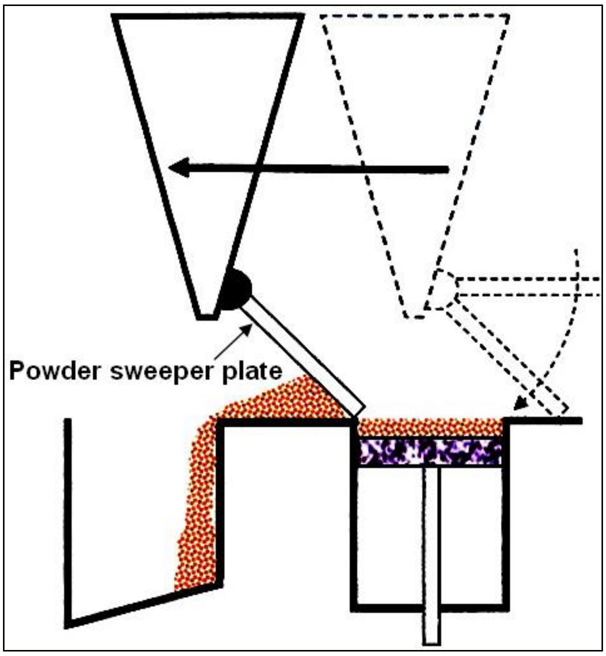


Fig-4 Step 2 of manufacturing process of green specimen, powder sweeper plate sweeps the pile of the powders

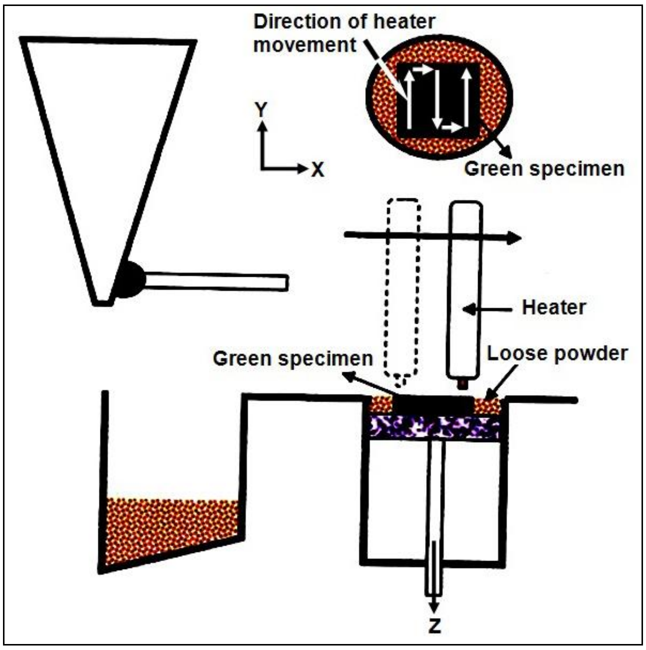


Fig-5 Step 3 of manufacturing process of green specimen, the heater move down approached the surface of the powder, then heating the powders

The amount of green specimens for the design size of (80mm x10mm x 10mm) was 15 pieces. Green specimens were divided into three groups. Group 1: green specimens were not reheated, tests performed for bending strength. Group 2: green specimens were heated at a temperature of 700°C; tests performed for bending strength. Group 3: green specimens were heated at a temperature of 700°C and then impregnated by resin; tests performed for bending strength. Bending test that was performed, based on the ASTM D 790-07 standard, by three-point loading method. Fig-8b is the green specimen for bending test, that made by using SHM machine.

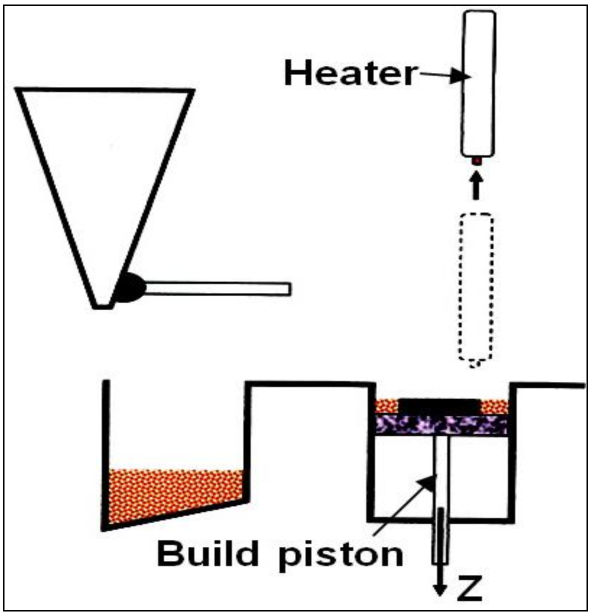


Fig-6 Step 4 of manufacturing process of green specimen, the heater moves up, and simultaneously build piston moves down to the distance of 1 mm

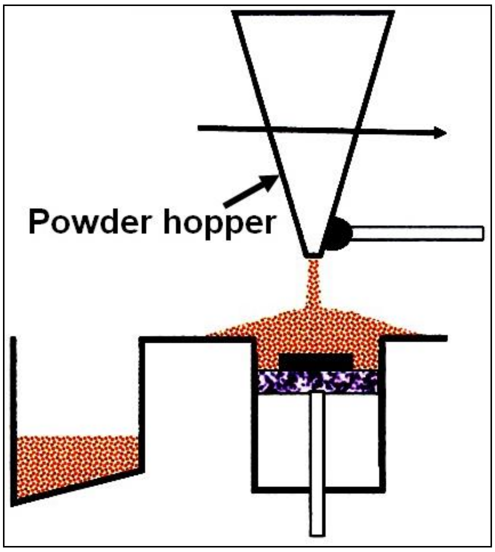


Fig-7 Step 5 of manufacturing process of green specimen, powders were fed into the build chamber from hopper

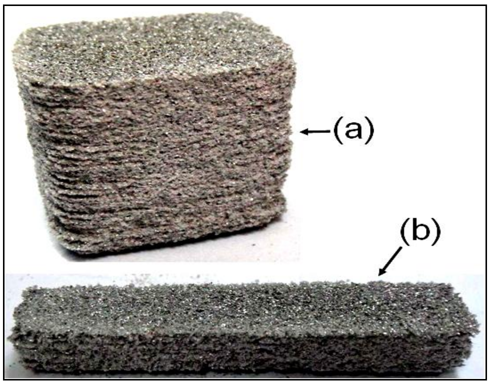


Fig-8 Green specimen made by SHM machine.
(a)Design size of (30mm x 30mm x 30mm);
(b) design size of (80mm x 10mm x 10mm)

2.3 Dimensional Error, Surface Roughness, and Surface Hardness Test.

Fig-9 shows the flowchart of manufacture of specimen, and tests of dimensional error, surface roughness, and surface hardness.

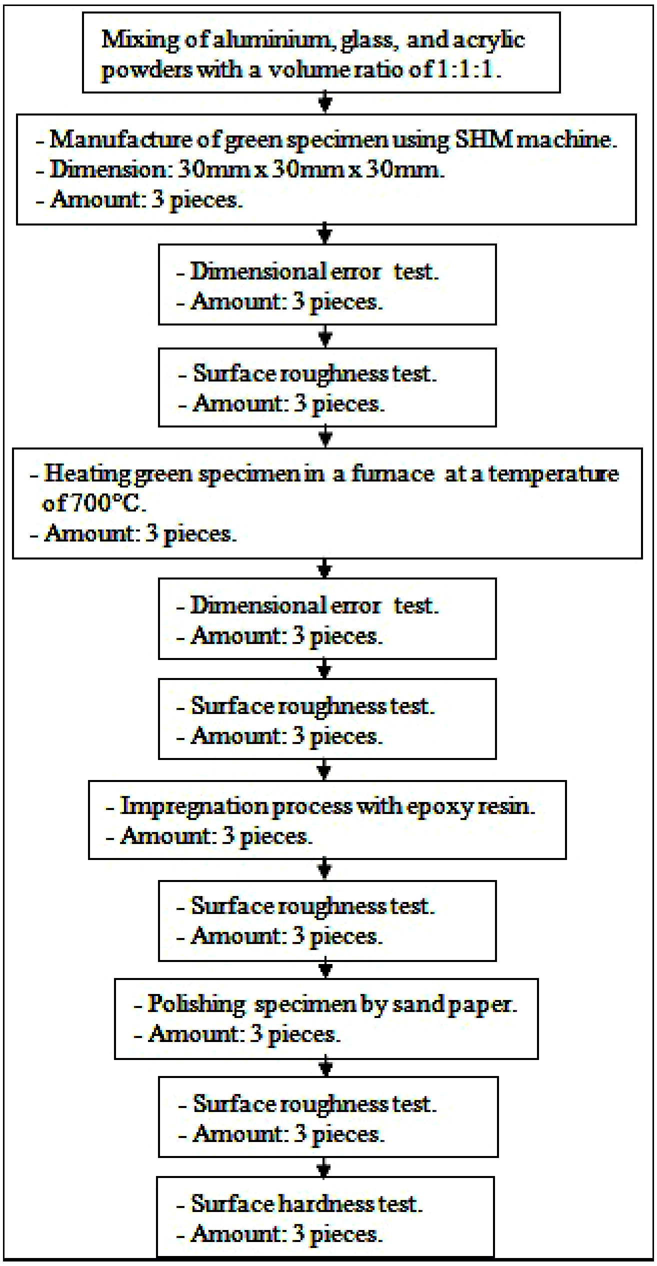


Fig-9 Flowchart of manufacture of specimen and tests of dimensional error, surface roughness, and surface hardness

The amount of green specimens for the design size of (30mm x 30mm x 30mm) was 3 pieces. Green specimens were divided into six groups. Group 1, green specimens were not reheated, the dimensions measured in the direction of X, Y and Z-axis; this data used for dimensional error calculation. Group 2, green specimens were not reheated, without polished (not smoothed); tests performed for surface roughness. Group 3, green specimens were reheated at a temperature of 700°C, the dimensions measured in the direction of the X, Y and Z-axis; this data used for dimensional error calculation. Group 4, green specimens were heated at a temperature of 700°C, without polished (not smoothed); tests performed for the surface roughness. Group 5, green specimens were heated at a temperature of 700°C, impregnated by resin, without polished (not smoothed); tests performed for the surface roughness. Group 6, green specimens heated at a temperature of 700°C, impregnated by resin, polished (smoothed) by the sandpaper of a grit number of 100 to 1000; tests performed for the surface roughness and for the surface hardness. Fig-10 shows the schematic of manufacturing of green specimen using Selective Heater Melting (SHM) machine. The heater move in the X-axis direction and Y-axis direction, while the build piston move in the Z-axis direction.

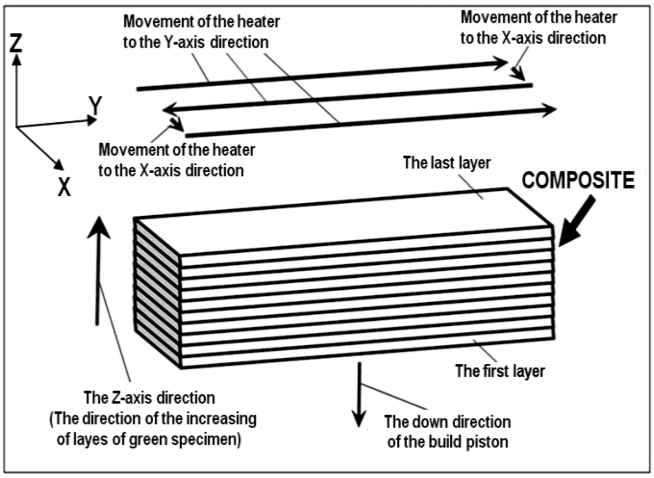


Fig-10 Schematic of manufacturing of green specimen using Selective Heater Melting (SHM) machine. The heater move in the X-axis direction and Y-axis direction, while the build piston move in the Z-axis direction

2.4 Reability Test of Insert Mold

Fig-11 shows the flowchart of manufacture of insert mold and reliability test. The mixture of aluminiumium, glass, and acylic powders was used for material of insert mold. Green insert molds, made by layer manufacturing method using Selective Heater Melting (SHM) machine. The amount of green insert mould was 2 pieces. Green insert molds (Fig-12), were heated at a temperature of 700°C, and then impregnated with the resin. The entire of the surface of the insert mold was polished by sand paper, and at the same time, the dimension of insert mold were adapted to the dimensions of steel mold. Finished insert mold (insert mold that has been polished, Fig-13), was mounted on the steel mold, as shown in the Fig-14. The reliability test was done by using the mold in the operation of plastic injection machine in industry. Product made by plastic injection machine was sliding plastics (Fig-15), made of HDPE (High Density Polyethylene). The function of finished insert mold was to make a hole of slider plastics as shown in Fig-15. Reliability test was done by counting the number of slider plastics that produced by mold till the finished insert molds were fractured.

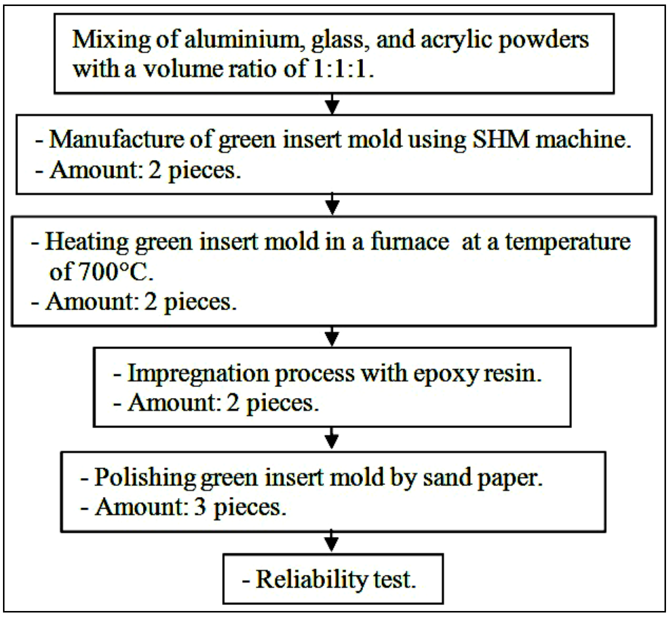


Fig-11 Flowchart of manufacture of insert mold and reliability test

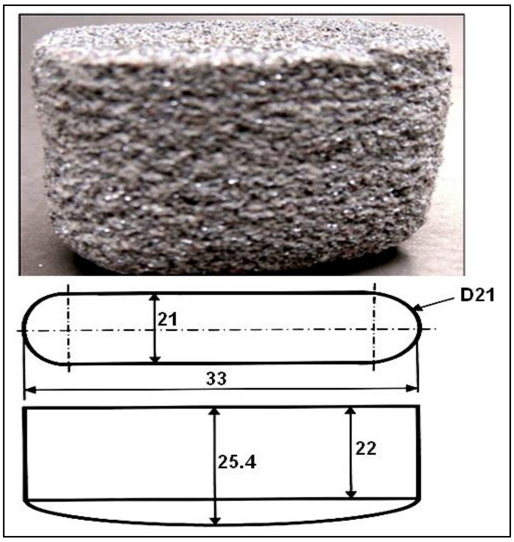
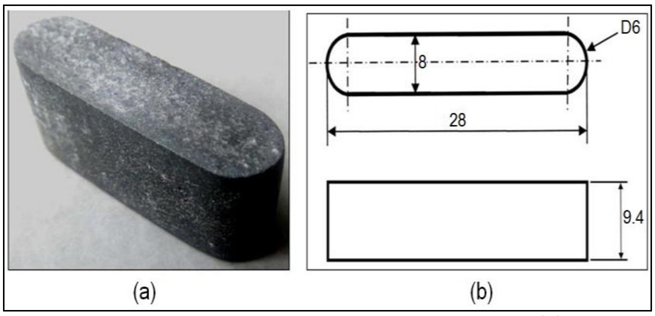


Fig-12: Green insert mold and of the dimension



(a) (b)

Fig-13 (a) Finished insert mold; (b) dimension of finished insert mold

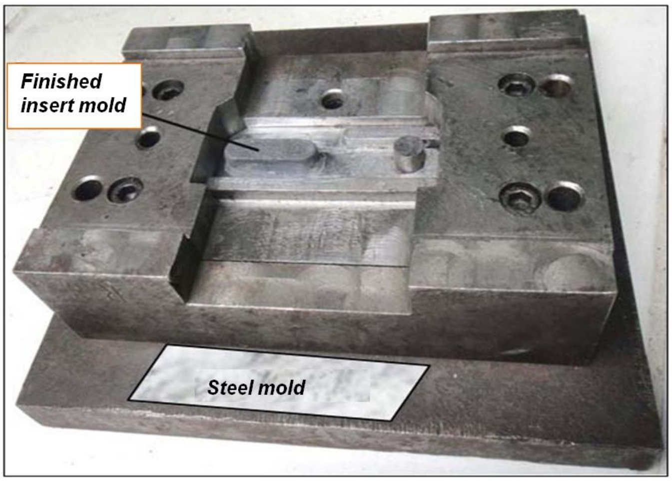


Fig-14 Finished insert mold (made of composite) mounted on the steel mold

Fig-15 Slider plastic

3. RESULTS AND DISCUSSION

Table-1 and Fig-16 are the bending strengths of the green specimens before and after heating at a temperature of 700°C, and the bending strengths of the green specimens after heating at a temperature of 700°C and resin impregnation. In these, among those measurement results, specimen with heating at 700°C and then impregnated with the resin shows the highest bending strength. The bending strength of green specimen before heating at 700°C was 1.86 ± 0.20 MPa. This bending strength was higher than that of Yan’s results i.e 1.4 MPa [25]. This composite was formed due to the melted acrylic bind the particle of glass and aluminum as depicted in Fig-17a. In term of bending strength, this green specimen was feasible as a material of green part. After heating at temperature 700°C, the bending strength increased to 7.85 ± 0.49 MPa. At this temperature, acrylic was burn out and at the same time, glass particle start to be softening and to bond the alumnum particle. There was in agreement with Liu, et al. [23], that bonding between the glass and the aluminum occurred due to the diffusion bonding.

Table-1 Bending strength of specimens

Bending strength of the green specimens before heating at 700°C. (MPa)	2.07 1.54 1.76 1.94 1.72
Bending strength of the green specimens after heating at 700°C. (MPa)	8.08 8.23 7.92 8.06 6.99
Bending strength of the green specimens after heating at 700°C and then impregnated by resin. (MPa)	17.15 16.94 16.43 17.09 16.05

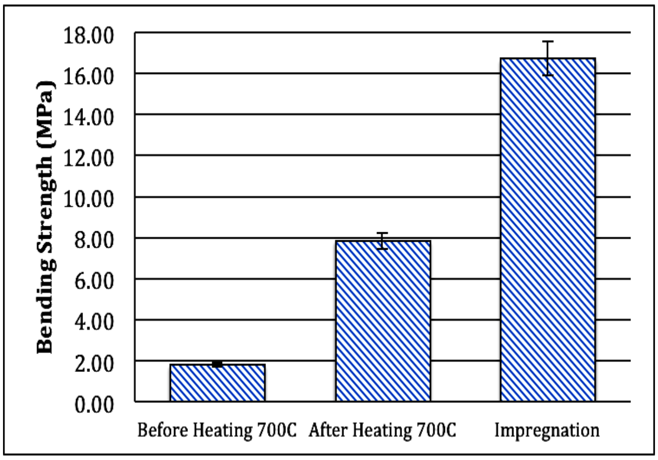


Fig-16 Effect of the treatment of the specimens to the bending strength

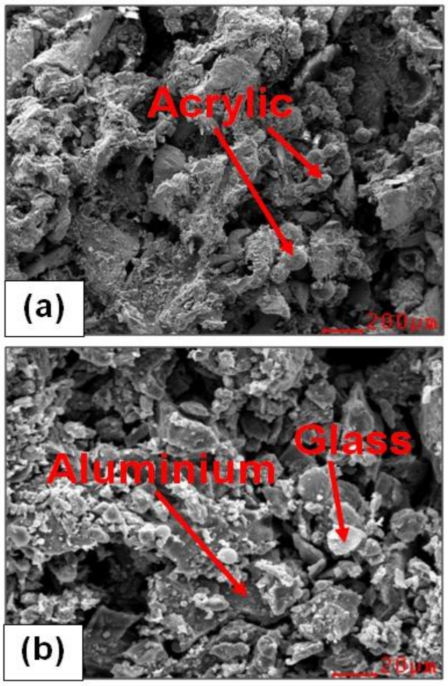


Fig-17 (a) Surface fracture of green specimen before heating at 700°C, most of the surface is covered by acrylic; (b) Surface fracture of green specimen after heating at 700°C.

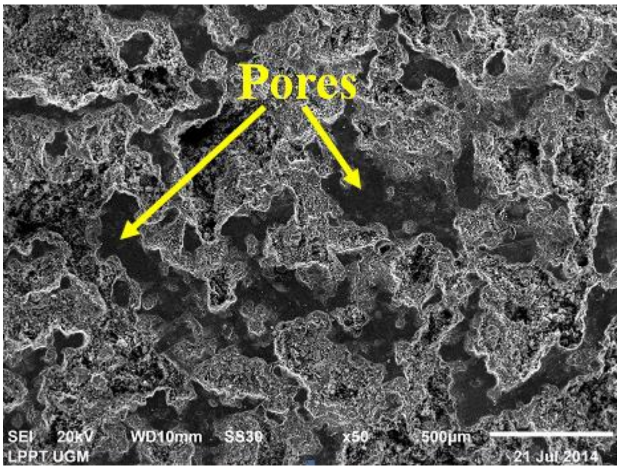
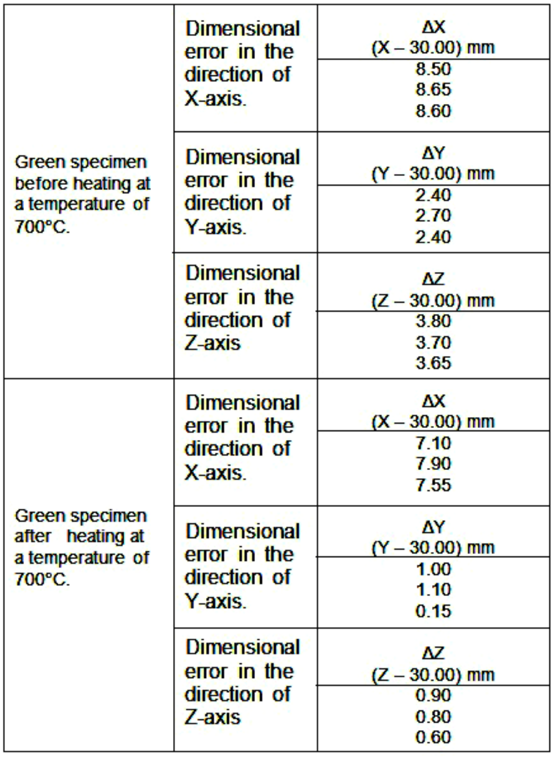


Fig-18 Green specimen after heating at a temperature of 700°C. Pores accurred because the acrylics were burned.

Na^+ ions move away from the interface of glass-aluminum, whereas oxygen ions diffuse into that region, and react with the silicon (Si) to form Si-O bonding. After heating, the specimen still performed better bending strength as contribution of glass bonding as shown in Fig-17b. There were pores in the specimen as a replacement of the acrylic position that has been burn out (Fig-18). For the specimens that has been impregnated by resin show much higher bending strength compared to that of the specimen that only treated by heating. The bending strength of this specimen was 16.73 ± 0.47 MPa. This was about twice of the heated specimen and almost 10 times to the green specimen that before being heated at 700°C. Impregnation of resin in the specimens could improve the bending strength. However, the bending strength of present work was still far below comparing to bending strength of Bernardo et.al work of 65.40 ± 9.32 MPa [8], and Montazerian et al. work of 132.47 ± 13.80 MPa [9]. Dimensional errors, that expressed by the difference of the dimension of design (computer) and the dimension of specimens in 3-axes direction (x, y and z axes), show that there was over size in x-direction, higher than that of y and z-directions before and after heating as depicted in Table 2 and Fig-19. The over size in x, y and z-direction of the green specimen before heating were 8.58 ± 0.07 mm, 2.50 ± 0.17 mm and 3.71 ± 0.07 mm, respectively; and after heating there were 7.51 ± 0.40 mm, 0.75 ± 0.52 mm and 0.76 ± 0.15 mm, respectively. In these, over size that happen to the green specimen before heating was higher than that after heating. It was about 10 % differences. There was any shrinkage after the acrylic burn out and re-arrangement of glass and aluminum particles resulting the pore size decreased. These over size in general might be due to the loose powder located outer ring of the desire size reach the caking temperature and solidified after cooling down. The dimensional error in the direction of the X-axis (ΔX) was differ with that of in the direction of the Y-axis (ΔY). It was caused by the pat-tern of movement of the heater, as shown in Fig-10. The path length of movement of the heater on the direction of the Y-axis, was greater than that in the direction of the X- axis; and also, backward and foreward movement of the heater in the direction of the Y-axis causing the heat flowed to the lateral direc-tion (X-axis direction) was greater than that of the Y-axis direction (Fig-20). So that the dimensional error in the direction of X-axis was greater than dimensional error in the direction of Y-axis. The dimensional error of the green specimen at the direction of Z-axis (ΔZ) was due to the effect of the heat that flowed on the direction of Z-axis. Fig-21 shows a schematic of part of the powder mixture of which undergo hardening (bonding) after the heater passed over the first time. Fig-21 shows, maximum thickness was 1.1 mm, exceeded the thickness that was designed for each layer (i.e 1 mm), thus the bonding between the layers was always occurred. The actual length of each step of the movement of the heater, in the X-axis direction was 0.95 mm. Fig-19 shows the layer building along hatch vectors. A hatch vector refers to the path that the heater has to follow within a contour to build a portion of the layer [30]. When the manufacture of the layer was in progress, the additional of the heat takes place on the layer that was formed previously; heat flows from the layer being formed, toward the layer below it (at the Z- axis direction). The addition of the heat from the top caused the loose powders, that were directly in contact with the upper layer, reached the temperature above a caking temperature, resulting in secondary heating [25]. In the surface roughness test of the specimens shown in Table 3 and Fig-22, showed that the surface roughness of the green specimens were the highest comparing to that of the specimen after heating and impregnation. It may be due to the nature of selective heater melting process i.e. there aren’t compaction process. Improve-ment of the surface roughness could be carried out by impregnation and polishing. In the current work, impregnation was done by resin and polishing by sand paper with grit number of 100 and 1000. Applying these, the finished specimens have an average value of the surface roughness $Ra_m = 2.454$ µm as illustarted in Table 4. This roughness was still larger than that of the mold which generally used in plastic injection molding industry, i.e 0.2 µm [2]. Beyond the surface polishing, improvement of the surface finish probably could be done by using finer particle size of particle.

Table-2 Dimensional error of green specimen



Green specimen before heating at a temperature of 700°C.	Dimensional error in the direction of X-axis.	ΔX (X – 30.00) mm
		8.50 8.65 8.60
	Dimensional error in the direction of Y-axis.	ΔY (Y – 30.00) mm
		2.40 2.70 2.40
	Dimensional error in the direction of Z-axis	ΔZ (Z – 30.00) mm
		3.80 3.70 3.65
Green specimen after heating at a temperature of 700°C.	Dimensional error in the direction of X-axis.	ΔX (X – 30.00) mm
		7.10 7.90 7.55
	Dimensional error in the direction of Y-axis.	ΔY (Y – 30.00) mm
		1.00 1.10 0.15
	Dimensional error in the direction of Z-axis	ΔZ (Z – 30.00) mm
		0.90 0.80 0.60

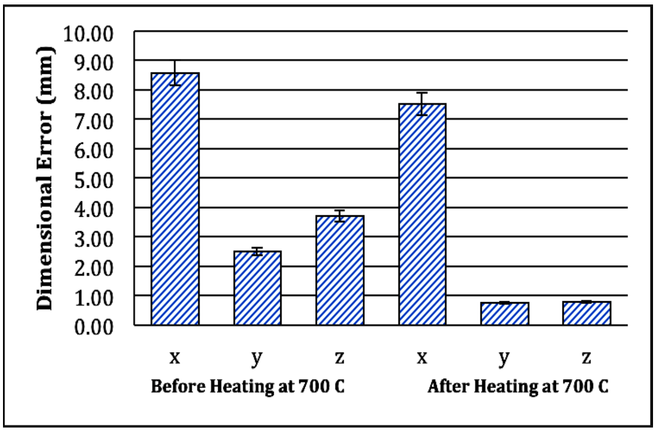


Fig-19 Dimensional error of the green specimens before and after heating at a temperature of 700°C

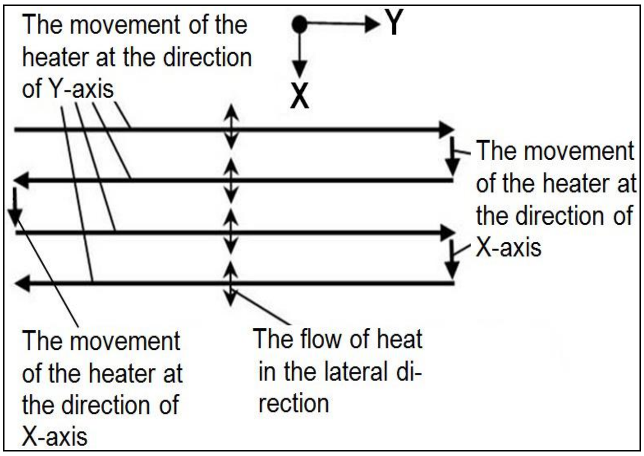


Fig-20 The pattern of the movement of heater. Movement of the heater back and forth in the direction of Y-axis, causing the amount of the heat flows to the direction of the X-axis (lateral direction) was greater than the direction of Y-axis

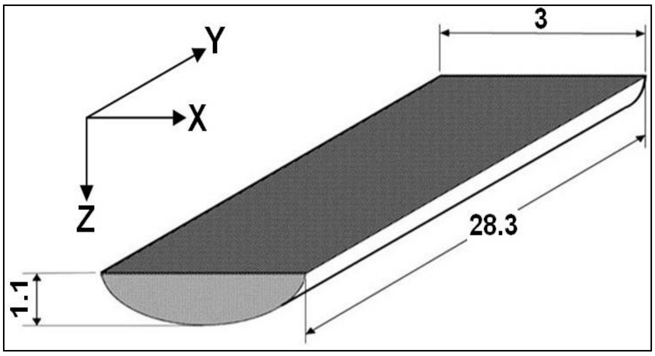


Fig- 21 Schematic of shape and dimension of the powder mixture, that was hardened (i.e: bonding was occurred between the powder particles), after being heated by the heater, at the first path.

Table-3 Surface Roughness of Specimens

The surface roughness (Ra) of the green specimens before heating at 700°C. (µm)	36.81 37.70 46.12
	Mean: 40.21
The surface roughness (Ra) of the green specimens after heating at 700°C. (µm)	26.37 23.66 33.48
	Mean: 27.83
The surface roughness (Ra) of the green specimens after heating at 700°C and then impregnated by resin. (µm)	12.17 11.57 11.57
	Mean: 11.91

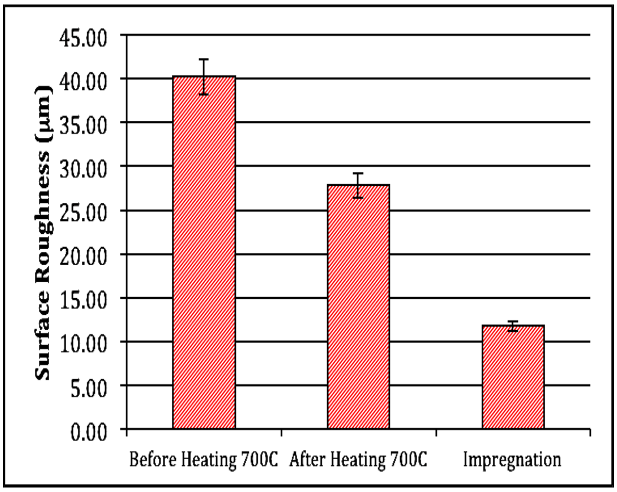


Fig-22 Surface roughness of green specimen before and after heating at 700°C, and after impregnating by resin

Table-4 Surface roughness of finished specimen

No.	The surface roughness of the finished specimens (specimens that was impregnated by resin, and then the surface was polished by sandpaper), Ra (µm).
1.	2.476
2.	2.845
3.	1.936
4.	2.192
5.	2.821
Mean	2.454

In this present work, surface hardness was only carried out for the specimen that treated with heating at 700^{o}C, impregnation and surface polishing. The hardness of surface finished specimens was shown in Table 5. The average of the surface hardness of finished specimen was 13.02 BHN. Comparing to that of existing mold which manufactured by machining of tin-bismuth alloy bulk (20 BHN) and steel bulk (122 BHN) [1], this hardness was smaller.

Table-5 Surface hardness of finished specimen (BHN)

No.	The surface hardness of the finished specimens (specimens that was impregnated by resin, and then the surface was polished by sandpaper), BHN.
1	12.960
2	11.879
3	11.879
4	14.199
5	14.199
Mean	13.020

In the reliability test, in the first running test, the amount of products (slider plastics) was 120 pieces, and in the second running test there was 126 pieces. The number of part that could be produced much lower than that has been conducted by Pham, et al. [5]. However, the composite of the mixture of the aluminum, glass, and acrylic powders would be still useful and applicable for small lots for plastic part product. The number of part will be much improved probably for injecting functional part with another material that has lower melting point such as wax based composite. Another application is for prototyping part.

4. CONCLUSION

Particulate composite of Aluminum-Glass-Acrylic powders has been developed successfuly and tested for mechanical strength. The insert mold made of this composite material using Selective Heater Melting machine have also been tested for running production. Tests have been carried out for green specimen, after heating and impregnation without and with polishing, and tests also have been carried out for insert mold. These tests included bending, dimensional error, surface roughness and hardness as well as reliability. Based on these, it can be concluded that resin impregnated specimen with polishing show the highest bending strength (16.73 ± 0.47 MPa) and surface hardness (13.02 ± 1.16 BHN) and the most fine surface finish (2.454 µm). While for dimension error, heating at 700^{o}C for the green specimen could reduce dimensional error. In reliability test, however, the injection mold with insert mold made of this particulate composite could produce 120 and 126 pieces of slider plastics. Although, it was smaller than that of common injection mold, this material was less expensive and would have prospect to be used for small lots production that currently small number and custome product demand become a new trend in consumer industry.

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REFERENCES

[1]. Menges, Mohren, 1986, How to Make Injection Molds, Hanser Publishers Munich Vienna New York, 1986, pp. 7-21.

[2]. Rees, H., 2002, *Mold Engineering*, Second Edition, Hanser Publishers, Munich.

[3]. Jetley, S., Low, D.K., 2006, A Rapid Tooling Technique Using a Low Melting Point Metal Alloy for Plastic Injection Molding, *Journal of Industrial Technology*, Volume 22, Number 3 – July 2006 through September 2006.

[4]. Doehler, H.H., 1951, *Die Casting*, McGRAW- HILL BOOK COMPANY, INC, New York, pp. 117-118.

[5]. Pham, D.T., Dimov, S., Lacan, F., 1999, Selective Laser Sintering: Applications and Technological Capabilities, *Proceedings of the Institution of Mechanical Engineers*, Vol 213 Part B: *Journal of Engineering Manufacture* 1999 213: 435, DOI: 10.1243/0954405991516912.

[6]. Ilyas, I., Taylor, C., Dalgarno, K., Gosden, J., 2010, Design and Manufacture of Injection Mould Tool Inserts Produced Using Indirect SLS and Machining Processes, *Rapid Prototyping Journal*, Volume 16/Number 6 (2010) 429-440, Emerald Group Publishing Limited [ISSN 1355-2546].

[7]. Vallabhajosyula, P., Bourell, D.L., 2011, Modeling and Production of Fully Ferrous Components by Indirect Selective Laser Sintering, Rapid *Prototyping Journal*, Vol. 17 Iss: 4, pp.262-268, Emerald Group Publishing Limited.

[8]. Bernardo, E., Scarinci, G., Hreglich, S., 2003, Mechanical properties of metal-particulate lead-silicate glass matrix composites obtained by means of powder technology, *Journal of the European Ceramic Society 23 (2003)*, pp.1819-1827.

[9]. Montazerian, M., Alizadeh, P., Yekta, B.E., 2008, Presureless sintering and mechanical properties of mica glass-ceramic/Y-PSZ com-posite, *Journal of the European Ceramic Society* 28 (2008), pp.2687-2692.

[10]. Rajesh,S., Jantunen, H., Letz, M., Wilhelm, S.P., 2012, Low Temperature Sintering and Dielectric Properties of Alumina-Filled Glass Composites for LTCC Applications, *International Journal of Applied Ceramic Technology, Int. J. Appl. Ceram. Technol.*,9[1] 52-59 92012). DOI:10.1111/j.1744-7402.2011. 02684.x.

[11]. Kim, K.S., Shim, S.H., Kim,S., Yoon, S.O., 2010, Sintering Behaviour and Dielectric Properties of Ceramic/Glass Composites Using Lead Borosilicate Glass, *Journal of Ceramic Processing Research*, Vol. 11, No.1, pp. 35-39.

[12]. Darmo, S., Tontowi, A.E., Suyitno, Mahardi-ka, M., 2013, Aluminium-Particulate Glass Matrix Composites with Acrylic as a Binder for a Plastic Injection Mold Material, *International Journal of Materials Science*, ISSN 0973-4589 Vol. 8, No.2, pp. 57-78.

[13]. Darmo, S., 2013, Kekuatan Lentur Komposit Matriks Kaca Limbah dengan Penguat Partikel Aluminium Limbah yang Dibuat dengan Metode Tanpa Penekanan, *Prosiding Seminar Nasional Teknologi Terapan*, ISBN 978-602-14066-2-5 Vol. 1B, No.1, pp. 367-374.

[14]. Darmo, S., Tontowi, A.E., Suyitno, Mahardika, M., 2014, Pengaruh Kecepatan Gerak Pemanas Radiasi dan Perbandingan Volume Bahan Baku Komposit Terhadap Ikatan Partikel Hasil Proses *Indirect Layer Manufacturing*, *Prosiding Seminar Nasional Perkembangan Riset dan Teknologi di Bidang Industri ke 20*, ISBN 978-602-70455-0-7, pp. BT-MB- 84.

[15]. Altenpohl, D., 1982, *Aluminium Viewed from Wi-thin*, first edition, Printed in the Federal Republic of Germany, pp.171.

[16]. Parker, E.R., 1967, *Materials Data Book*, Mc-Graw-Hill, New York.

[17]. Cary, H.B., 1979, *Modern Welding Technology*, First Edition, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, pp.436.

[18]. Poinern, G.E.J., Ali, N., Fawcett, D., 2011, Prog-ress in Nano-Engineered Anodic Aluminium Oxi-de Membrane Development, *Materials* 2011, 4, 487; doi: 10.3390/ma4030487, ISSN 1996-1994.

[19]. Avner, S.H, 1988, *Introduction to Physical Metallurgy*, Second Edition, McGRAW-HILL BOOK COMPANY., New Delhi, pp.493-494.

[20]. Kolarik, V., Lorenzo, M.M.J., Fietzek, H., 2011, Oxidation of Micro-Sized Spherical Aluminium Particles, *Materials Science Forum*, Vol. 696 (2011),doi10.4028/www.scientific.net/MSF. 696. 290, pp. 290-295.

[21]. Gokce, A., Findik, F., 2008, Mechanical and Physical Properties of Sintered Aluminium Powders, *Journal of Achievements in Materials and Manufacturing Engineering*, Volume 30 Issue 2 October 2008, ISSN 1734-8412.

[22]. Gutin, S.S., Panov, A.A., Khlopin, M.I., 1972, Effect of Oxide Films in The Sintering of Aluminium Powders, *Powder Metallurgy and Metal Ceramics, Journal no. 11106*, Volume 11, Issue 4, ISSN 1068-1302, pp. 280-282.

[23]. Liu, C.R., Zhao, J.F., Lu, X.Y., Meng, Q.S., Zhao, Y.P., Munir, Z.A., 2008, Field-assisted Diffusion Bonding and Bond Characterization of Glass to Aluminum, *J Mater Sci (2008) 43:5076–5082*, DOI 10.1007/s10853-008-2583-4

[24]. Smith, W.F., 1990, *Principles of Materials Scien-ce and Engineering*, Second Edition, McGraw-Hill Publishing Company, New York.

[25]. Yan, C.Z., Shi, Y.S., Yang, J.S., Liu, J.H., 2009, Preparation and Selective Laser Sintering of Nylon-Coated Metal Powders for The Indirect SLS Process, *Rapid Prototyping Journal*, volume 15, number 5, pp. 355-360, Emerald Group Publishing Limited, ISSN: 1355-2546.

[26]. Polymer Data Handbook, 1999, Oxford University Press, Inc., pp.226.

[27]. Raghavan, V., 1990, *Materials Science and Engineering*, Third Edition, Prentice-Hall of India, New Delhi, pp.217.

[28]. Levitas, V.I., 2013, Mechanochemical mecha-nism for reaction of aluminium nano- and micrometre-scale particles, *Royal Society Publishing*,DOI: 10.1098/rsta.2012.0215Published 28 November 2013.

[29]. ASM HANDBOOK Volume 14, 1996, *Forming and Forging*, ASM Hanbook Committee.

[30]. Choi, S.H.and Samavedam, S., 2001, Visualisa-tion of rapid prototyping, *Rapid Prototyping Journal*, *Volume 7, Number 2, 2001*, MCB University Press, ISSN 1355-2546, pp. 99-114.