# GLUE INFILTRATION OF FREEFORM FABRICATION PRODUCT OF CAST IRON-PE/SILICA-PE COMPOSITE

**Susilo Adi Widyanto, Alva Edy Tontowi, Jamasri and Heru Santosa Rochardjo**
Department of Mechanical Engineering, Faculty of Engineering, Gadjah Mada University
Jl. Grafika 2 Yogyakarta, Indonesia. Phone & fax 0062-274-513668
Email : susilo70@yahoo.com

**ABSTRACT**

*Due to the pressure-less sintering process, products of the SFF are commonly weak so that the strengthening process is needed. This paper reports a SFF product strengthening method with glue infiltration.*

*Material of the specimen used the powders of Cast iron-PE and Silica-PE blend with particles size of 100μm (150 mesh) and 150μm (100 mesh) while cyanoacrylate glue was used as infiltrant. The sintering process was run at the temperature of $135^0$C and holding time of 2.5 hours. The product was shaped in the tensile strength, the density and the shrinkage test specimens. Before infiltration, a part of the specimens were burned out to increase the pores. The experiment was also conducted to observe the influence of curing process after infiltration on the tensile strength with varying curing temperature which includes $50^0$C, $75^0$C and $100^0$C.*

*The experiment results show that the tensile strength of the cast iron-PE as well as silica-PE composite is significantly increased by glue infiltration. An increase in the tensile strength achieves around of 1100%.*

**Key words: infiltration – cyanocrylate – curing - sintering**

## INTRODUCTION

Layer manufacturing is proven as a process that can help to rapidly provide feedback on design concepts, discover inconsistencies in the design, modify the design, and eliminate inconsistency before fabricating the design. This greatly reduces the production cycle time, and tremendously contributes to quality, competitiveness, and reduction in maintenance cost (Tseng and Tanaka, 2001). Generally the layer manufacturing technology does not require pre-formed mandrel or tooling; instead, it builds physical objects directly from computer image data and it constructs the three dimensional object layer by layer (Beaman *et al*, 1997).

In layer manufacturing process, some materials have been used ie: metal, polymer, ceramic or mixing of both, however polymer is a common material. This paper reports a using polyethylene as a binder of cast iron-PE/silica-PE composites which were produced by the multi materials deposition-indirect sintering process (MMD-Is). According to the material properties, particularly the difference of the melting temperature between cast-iron/silica and polyethylene, the binding mechanism is produced with liquid phase sintering.

## THEORY

### Liquid Phase Sintering (LPS)

In LPS system, the liquid may provide for rapid transport and therefore rapid sintering if certain criteria are met (Lenel, 1980). The liquid must form a film surrounding the solid phase. Thus, wetting is the first requirement. Secondly, the liquid must have solubility for the solid. Finally, the diffusive transport for the solid atoms dissolved in the liquid should be high enough to ensure rapid sintering (Huppmann,1975). In the liquid phase sintering, the densification rate is much faster than in solid state sintering, and times as short as 15 min at the maximum temperature can be successful in producing full density (German,1996).

On liquid phase sintering, shrinkage gradients in a compact sintered powder traditionally attributed to gradient in green density. Reduced shrinkage during sintering at the bottom of the compacts is attributed to the friction between the compacts and the substrate material (Gurland,1962).

Densification and shape distortion during liquid phase sintering depend on the driving force and the resistance to viscous deformation (German,1996). Liu *et al* (1999) presented that the capillary force was used the driving forces of densification and surface tension and gravitational were used the driving force of shape distortion.

### Infiltration Process

In MMD-Is, the sintering process is executed in pressure-less condition. Product powder as well as supporting powder is only deposited without compaction. Here, depositing product powder and supporting powder used a screw feeder hopper nozzle and slot feeder counter rolling cylinder, respectively. To shape the product, the screw feeder hopper nozzle moves to deposit a product powder which match to the 2D data image resulted by slicing process. The altering layers are carried out with depositing supporting powder to cover and to stabilize the position of the deposited product powder.

Due to the pressure-less sintering, the MMD-Is product has a low mechanical strength, therefore the continued process is needed to increase it. One method is infiltration process.

The mechanism of infiltration process is explained: for a wetting liquid melt, the capillary pressure $\Delta P$ varies with the inverse of the pore size d as follows:

$$\Delta P = 2\gamma \cos(\theta)/d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where $\gamma$ is the surface energy of the liquid and $\theta$ is the contact angle. A good example is copper infiltration of iron. Capillary wicking of the liquid copper occurs due to the small pore sizes and low contact angle. As is evident in Figure 1, the capillary pressure causes liquid to flow into the open pore structure.

Although the flow of the liquid into the pores is beneficial, there are also some possible problems with infiltration. Typically the infiltrant is formed on one surface of the sintered material and capillary action draws the liquid into the pores. Because of the directional flow of the liquid, it may erode the surface from which the infiltrant is fed. For that reason, infiltration cycle times are short, to keep dimensional changes to less than 2%. Also since the capillary pressure scales with the inverse of the pore size there is little driving force for infiltration of large pores. Since the large pores are most detrimental to properties, for maximum benefit, one must ensure they are filled.

The ideal infiltrant will completely fill the pore space, exhibit good flow and

wetting of the pore structure, and will not leave a residue. For iron, the copper infiltrants contain nickel, manganese, aluminum, and carbon, or zinc to achieve the desired characteristic (German, 1994).

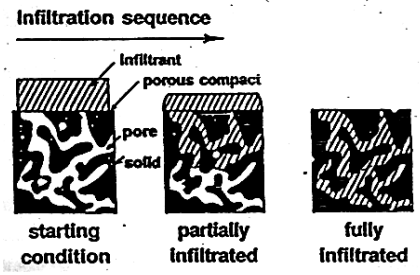


**Figure 1. A sketch of the infiltration sequence where capillary force pull a molten metal into the open pores of a sintered compact (German, 1994)**

## METHODOLOGY

### Material and specimens preparation

Materials of the specimens consisted of the cast iron-PE and silica-PE blend powder. By multi material deposition-indirect sintering machine, these materials were formed into the specimens of tensile strength test. Specimens were made by varying the composition (cast iron-PE as well as silica-PE or both (multi material)), particle size, curing temperature and burn out process.

**Table 1.** Properties of polyethylene and silica

| | **Polyethylene** | **Silica*)** |
|---|---|---|
| Chemical formula | $(C_2H_4)_x$ | 99% $SiO_2$ |
| Density | 0.93 gr/cm$^3$ | 2.65 gr/cm$^3$ |
| Melting point | 138$^0$C | 1830$^0$C |
| Tensile strength | 1400 to 3010 psi | 55 MPa |

*) www.azom.com

The infiltration process was executed with dying the specimens in the glue along 30 second (this time was determined with assuming that the glue had filled up in all the pores of the specimen). Variation of the particle size and curing temperature of the specimens are 100µm (150 mesh), 150µm (100 mesh) and 50$^0$C, 75$^0$C, 100$^0$C, respectively. Before curing, a part of the specimens were burned out at a temperature of 250$^0$C during 2.5 hours. This process was aimed to increase the pores of the product material with evaporation process of PE (melting point of PE is around of 138$^0$C). For clarification the influence of burn out process on the pores, both specimens (with and without burn out) are tested with the porosity testing.

**Table 2. Specification of the glue as an infiltrant (ALTECO KOREA INC, 1997)**

| | |
|---|---|
| Appearance | Colorless Transparent Liquid |
| Viscosity | 3CPS |
| Gravity | 1.04 ~ 1.08 |
| Main Ingredient | Cyanoacrylate |
| Solubility | With Acetone |
| CPS : Centi Poise (Viscosity Unit). The Viscosity of water is 1.01 CPS under the condition of 20¡É | |

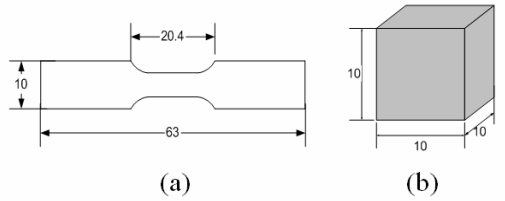


**Figure 2. a) The dimension of tensile strength test specimen accorded to ASTM D-638 standard, b) density and porosity test specimen.**

**Testing**

The tensile strength test employed the tensile test machine type of CE Pearson Panke. In this test, a jig is used to hold the specimen to prevent the failure of the specimen on the location of clamping. The type of machine and the construction of the jig are shown in Figure 3.

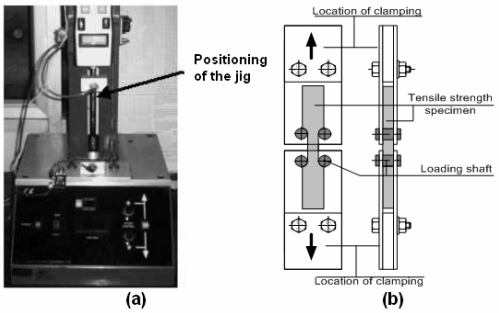


**Figure 3. a). tensile test machine, b) jig of the specimen**

## RESULTS AND DISCUSSION

By glue infiltration, the tensile strength of cast iron-PE increases from 0.46kg/mm$^2$ to 5.5kg/mm$^2$, while silica-PE from 0.45kg/mm$^2$ to 4.47kg/mm$^2$ (particle size 100μm). This generally means that the tensile strength of cast iron-PE composite is higher than that of silica-PE composite. The strength of binding mechanism among particles can be affected by the particle shape. Irregular composed particles yield the higher binding strength of the sintering product which is caused by the effect of geometric constrain. By observing particle shape of silica and cast iron powder will confirm this condition.

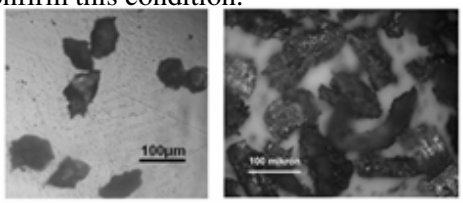


**Figure 4. The particle shape of : a) silica, b) Cast iron powder (by an optical microscope)**

According to Figure 4, the particle shape of cast iron powder is more random and the surface condition is coarser than that of silica powder. This explains the reasoning difference of the tensile strength of both materials.

For the multi materials specimens, the tensile strength increases from 0.016kg/mm$^2$ to 2.63kg/mm$^2$. The tensile strength testing shows that the fracture occurs at the boundary of the materials (between cast iron-PE and silica-PE). This means, the occurrence of binding strength between the difference materials is weaker than that of the one material.

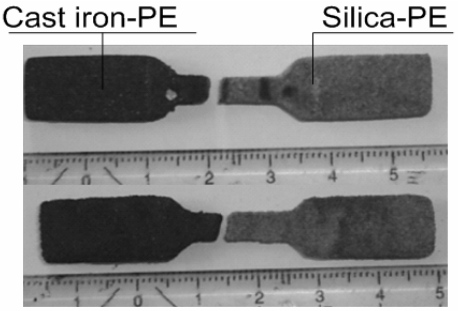


**Figure 5. Fracture of multi material specimen occurs at the boundary of the materials**

The Experimental results with varying curing temperature show that an increase in curing temperature enhances the tensile strength of both composites material. Curing temperature affects on the penetration ability of infiltrant material to fill the pores. An increase in curing temperature decreases the pores number un-filled by the infiltrant material. Correlation between curing temperature and tensile strength is shown in Figure 6 below:

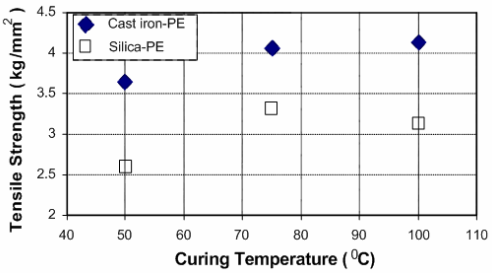


**Figure 6. Correlation between tensile strength and curing temperature**

Particle size of powder determines the tensile strength of product. An increase in particle size raises the empty space (pore) among particles. Due to the flow-ability limitation of infiltrant material, not all the pores are fully filled up by it. An increase in pore dimension enhances the total of empty space. It decreases the tensile strength of the product. This correlation is shown in Figure 7 below :

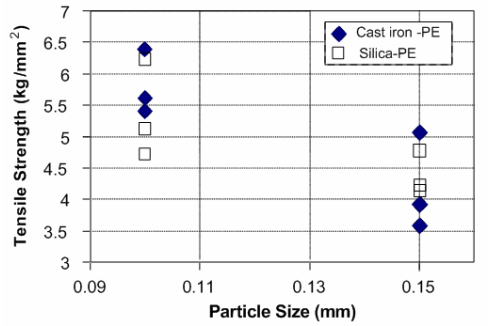


**Figure 7. Tensile strength is influenced by the particle size**

The result of density experiments shows that the glue infiltration process increases the density of product from 1.37g/mm$^3$ to 1.4g/mm$^3$ for silica-PE and from 1.38 g/mm$^3$ to 1.89g/mm$^3$ for cast iron-PE (particle size of 150µm). Due to the sintering at temperature of 135$^0$C as long as 2.5 jam, silica-PE specimen as well as cast iron-PE shrinks of 30.46 % and 19.69%, respectively. During curing process at the temperature of 50$^0$ (2.5 hours), the both specimens also shrinks until the total shrinkage achieves 30.88% and 19.94%. Completely the occurrence of the shrinkage of specimen is shown in Figure 7.

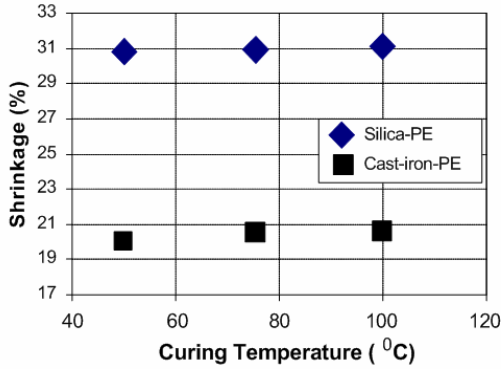


**Figure 8. Total shrinkage of the product caused by sintering process (temperature of 135$^0$C and holding time of 2.5 hours) and curing process**

By burn out process, the porosity of the product increases from 0.038% to 0.077% for Cast iron-PE (particle size of 150µm) and from 0.059% to 0.099% for Silica-PE (particle size of 150µm). By infiltration process an increase in the pores enhances the infiltrant (glue) filled up in it. With this process, the tensile strength of the Cast iron-PE and Silica-PE composite increase from 5.55kg/mm$^2$ to 5.79kg/mm$^2$ and from 4.77kg/mm$^2$ to 5.34kg/mm$^2$, respectively (particle size of 100µm). It means that an increase in the tensile strength of the part is produced by content of the glue, higher content of the glue causes higher tensile strength of the part.

Observed with scanning electron microscope (SEM), the structure of Cast iron-PE composite after sintering process, at a temperature of 135$^0$C and holding time of 2.5 hours is shown in Figure 9. This figure shows: due to the sintering process silica particle as supporting powder attached on the product surface (product

material is cast iron-PE) which is caused by melting PE. Figure 10 shows the occurrence of binding between silica and PE. The limited flow-ability of PE during sintering causes the occurrence of pores among particles. After infiltration process, the pores are filled up by the cyanoacrylate material, so that the empty space is reduced (Figure 11).

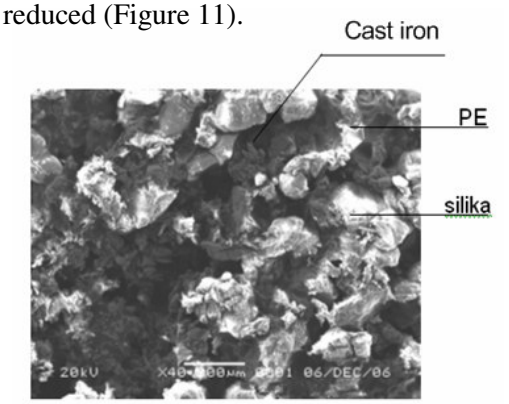


**Figure 9. The structure of cast iron-PE composite in which silica as supporting powder attaches on the product surface**

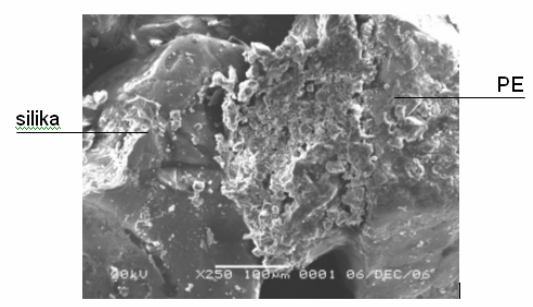


**Figure 10. Binding condition of silica and PE as the result of pressure-less sintering process (produced by MMD-Is machine)**

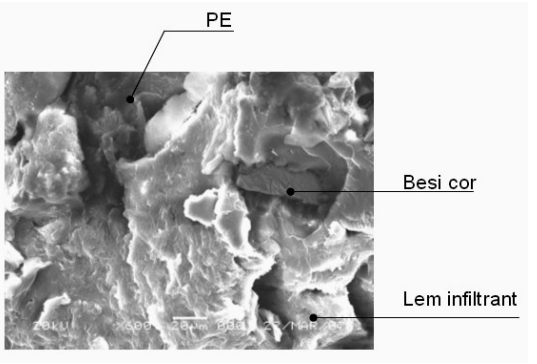


**Figure 11. The structure of the cast iron-PE composite after infiltration using cyanoacrylate (sintering temperature and holding time of $135^0$C and 2.5 hours, respectively)**

## CONCLUSIONS

By glue infiltration, the tensile strength of cast-iron-PE/Silica-PE composite material can be increased around of 11 x.

The glue infiltration which is continued with curing process improves the tensile strength of the product, however the total shrinkage also increases.

Burn out process increases the pores in the material structure of cast iron-PE as well as Silica-PE composite. Glue infiltration after burn out process improves the tensile strength and the density of the parts.

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