Effect of Pattern Coating Thickness on Surface Roughness and Porosity of Nodular Cast Iron (FCD) 450 Using Lost Foam Casting Method

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***Abstract*— Lost foam casting is one of casting method that uses expanded polystyrene (EPS) foam as a mold pattern and embedded into silica sand. When the molten metal is poured into a mold, EPS will melt and evaporate, so the cavity is filled by the molten metal. The main objective of this research was to investigate the effect of pattern coating thickness on surface roughness and porosity of nodular cast iron FCD 450 by using the lost foam casting method. The mold pattern of EPS foam has 17 kg/m^3 of density and 3-24 mm of section thickness. Coating material was used a refractory material of Zircon (ZrO_2) and binder of Colloidal Silica (O_2Si). In order to study effects of coating thickness, experiments were conducted with of 0-1300 µm. FCD 450 metal alloy was melted in a crucible furnace and the molten metal was poured into a mold at temperatures of 1350 °C-1450 °C. The experimental results showed the surface roughness decreases with increasing coating thickness of the EPS pattern. Uncoated of EPS pattern influenced the casting quality. The porosity increases with coating thickness of EPS pattern.**

***Index Terms*— lost foam casting, expanded polystyrene (EPS), nodular cast iron, surface roughness, porosity.**

I. Introduction

The demand for nodular cast iron product is increasing every year. Nodular cast iron is generally used for mechanical components, automotive parts and machine parts. This is mainly due to its relatively low cost, good mechanical properties, and to its excellent cast ability [1]. Ductile iron, also known as ductile cast iron, nodular cast iron, Spheroidal Graphite Iron (SGI) and Ferro Casting Ductile (FCD) iron. Nodular cast iron is basically included in a group of gray cast iron. The graphite that is found in ductile iron is shaped like nodules while the graphite in gray cast iron has a rod like random flaky pattern. Nowadays one of the most commonly nodular cast iron standard used is FCD 450.

Lost Foam Casting (LFC) is a type of evaporative-pattern casting process that is similar to investment casting. Lost foam casting is one type of casting that uses expanded polystyrene (EPS) material as a material for making patterns. This process takes advantage of the low boiling point of foam to simplify the investment casting process by removing the need to melt the wax out of the mold. LFC is an alternative method that can be used to produce a small amount, with a complicated shape is to use a casting method with a polystyrene foam mold pattern. Lost foam casting is one of the most cost effective casting method and environmentally friendly casting process [2]. Dry sand is compacted around a pattern made of expandable polystyrene (EPS) coated with a refractory material. When the molten metal is inserted into the mold, expanded polystyrene will melt and evaporate so that it will be filled by molten metal [2]. LFC has advantages such as the ability to produce complex shapes, dimensionally accurate, maintains an excellent surface finish, no parting line so no flash is formed, no cores [3] and reduced labor in the foundry practice. One of the important factors in choosing a casting method is dimensional tolerance. Dimension tolerance is the variation acceptable in the size of the final product. Another consideration is surface finishing. Very smooth metal surfaces are usually created with machining, which is extra cost. Choosing a casting method with a finer finish may reduce machining costs and some of automotive part section do not require surface finishing. Each type of casting method has advantages and disadvantages so that in the selection of production process by casting method must consider from various side either cost, quality, and function [1,2]. The quality of lost foam casting results is influenced by many parameters. These parameters include pouring temperature, expanded polystyrene (EPS) coating material type, silica sand mesh size, EPS density, vibration [4] object size, and material composition [1,2]. Researches on the effect coating thickness of polystyrene pattern on the lost foam casting have been carried out by some researcher. Guler [5] reported that pattern coating reduce the gas permeability and increase porosity however metal penetration into sand grains and surface roughening occurs without coating. There are several kinds of evaporative pattern coating with different thermo-physical characteristic, which are specially designed to meet number of requirements of the evaporative pattern casting process [6]. Karimian [7] used zircon flour coating for aluminum alloy whereas Trumbulovic [6] used kaolin and talc for the coating. Sodium silicate coating is not recommended because they lack permeability and can lead to metal splashing during mold filling. For the cast iron, a coating based on iron powder has been found successful in preventing metal penetration problems. Coating thickness and strip size had similar influences on the dendrite arm spacing (DAS) and at thinner coating layer cause reduction in the temperatures of both the start and finish points of solidification [8]. Karimian [3] reported that thinner pattern coating produced improved mould filling, refined microstructure and higher quality castings containing less porosity at an cast Al−Si−Cu alloy. Zircon flour,

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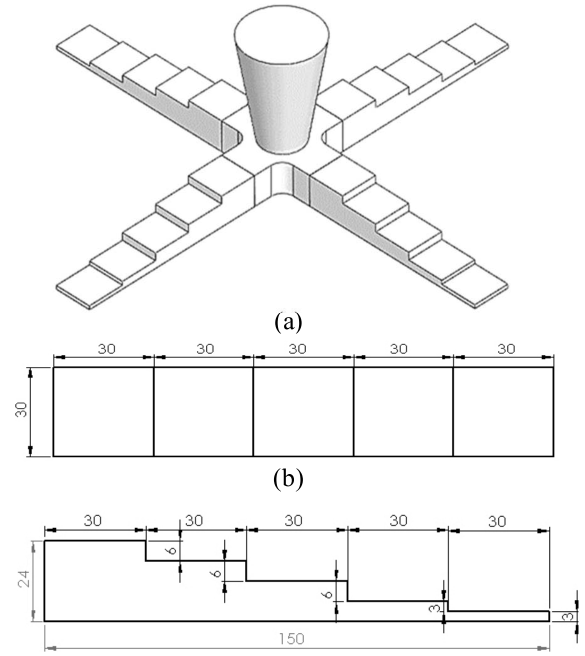
kaolin and talc as suitable refractory compositions were proposed for coating preparation in LFC of Al–7% Si [6]. /';In spite of coating materials, thickness of shell layer is other variable parameter affects the quality of castings [9]. The aim of this research is to know the effect of coating thickness of expanded polystyrene (EPS) pattern on surface roughness and porosity in FCD 450 nodular cast iron.

II. METHODS AND EXPERIMENTAL DETAILS

A. Preparation of Lost Foam Casting Patterns

The pattern is made from polystyrene foam, which can be done by many different ways. For small volume runs the pattern can be hand cut or machined from a solid block of foam and if the geometry is simple enough it can even be cut using a hot-wire foam cutter. If the volume is large, then the pattern can be mass-produced by a process similar to injection molding. The pattern material used in this experiment was expanded polystyrene (EPS). The EPS foam to be used in lost foam casting were prepared from a 17 kg/m^3 density polystyrene block [10]. Patterns with five different thickness levels as shown in Fig.1 have been designed and prepared for lost foam casting experiments using hot wire cutter with an accuracy of ± 0.5 mm. Pattern with 30 mm interval steps and 30 mm width were designed with different section thicknesses of 3, 6, 12, 18 and 24 mm. It aims to improve metal feeding during pouring. The four parts of the pattern were planned to be coated with refractory materials with different layer thicknesses. Then the uncoated pattern and the coated with the thickness variations were arranged on a cluster as shown in Fig.1.



(c)

Fig. 1. Lost foam casting pattern designed for experiments (a) isometric view (b) top view (c) side view (unit: mm)

B. Preparation of Pattern Coating Materials

Refractory materials used in this experiment were Zircon Oxide (ZrO2), and Colloidal Silica (O2Si). Coating analysis using zircon flour and Colloidal Silica as binder for considering cost economy. Zircon flour was found to be high properties of fire resistance, low dielectric constant, high density, high viscosity, and pH value nearer to neutral refractory [6]. Zircon material offer greatest resistance to penetration of metal into the mould, provide casting surface of high quality, show minimal reaction with all materials. Both of these refractory material (Zircon and Colloidal silica) were mixed with a composition ratio of 1:0.35. The temperature of the coating used in this investigation was 25ºC. The prepared coatings were applied on the surface of the samples. A coating method used in this experiment was immersing the pattern into the coating material mixture. A coating method conducted in this study is by immersion three times with detention time of immersion for 3 seconds. In the first dyeing process and drying time for 1.5 hours, a thickness of 200 µm was obtained. In the second dyeing with a drying time of 1.5 hours, a thickness of 500 µm was obtained and in the third dyeing with a drying time of 1.5 hours, a thickness of 1300 µm was obtained. After the patterns were coated, then dried for 1.5 hours with temperature 29-30ºC. Figure 2 shows the relationship between the intensity of the dyeing process and coating thickness of the EPS pattern.

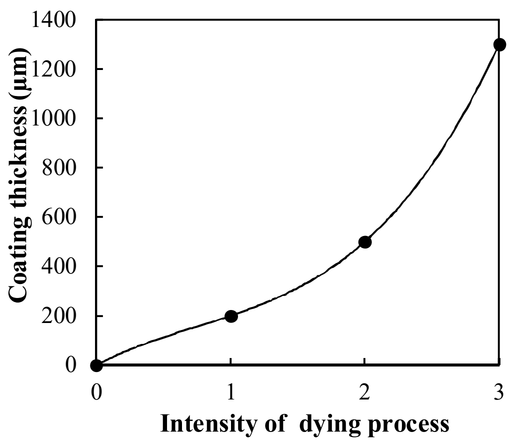


Fig. 2. The relationship between the intensity of the dyeing process and coating thickness of the EPS pattern with a detention time of 3 s.

The thickness of the coating material on the EPS pattern were obtained with different thickness of 200 µm, 500 µm and 1300 µm respectively as shown in Fig. 3. The thickness of coating material was measured using the Elcometer Wet Film Comb 112AL and vernier caliper. The four types of EPS pattern coating thickness were assembled into a single cluster as shown in Fig. 4. The cluster is placed into a flask and backed up with un-bonded sand were conducted to determine its effect on LFC casting surface roughness and porosity of nodular casting iron (FCD) 450.

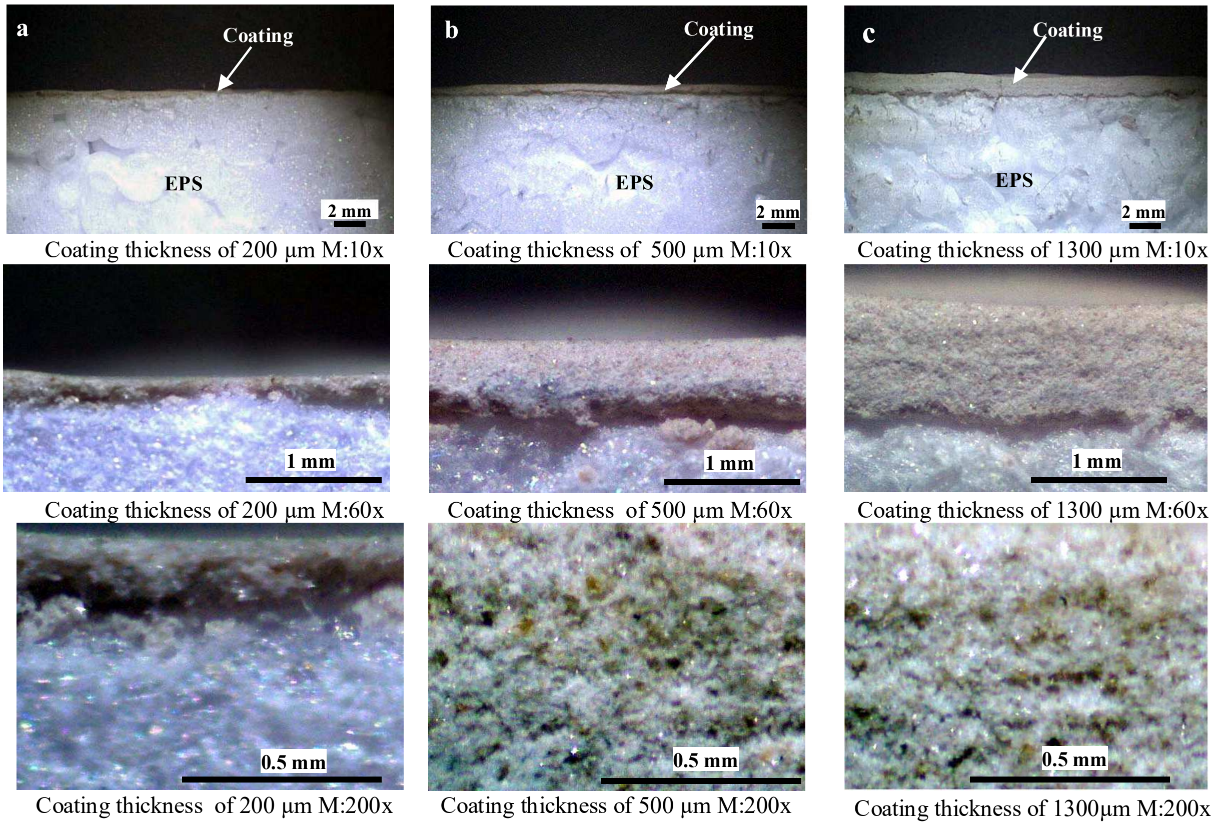


Fig. 3 The comparison image of EPS pattern coating thickness at layer thickness of 200 µm (a), 500 µm (b), and 1300 µm (c).

Fig. 3 shows that the mixture of Zircon refractory material, and a binder Colloidal Silica is excellent when used as a coating material on the pattern of lost foam casting method. It can be seen that the coating thickness is proportional to the amount of dyeing with 3 seconds waiting time, because of higher slurry viscosity produces a thicker layer. Due to the reduced permeability in the thicker coatings, gas escaping through the coating and mould sand is slower, which retards the downward flow of the metal and causes misrun and entrapped gases [3].

C. *Casting Preparation*

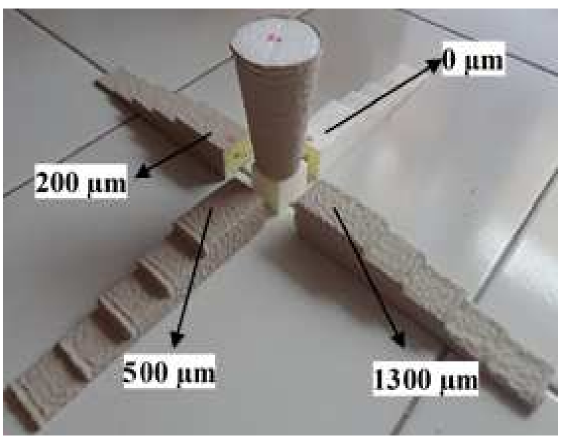


Fig. 4. Variation of EPS pattern coating thickness on lost foam casting were assembled into a single cluster

After the coating was dried, the mould was prepared using silica sand (AFS No.50–60) and vibrated at a frequency of 23 Hz by using vibrator machine. The moulds were compacted for the durations of 3 min. Nodular cast iron FCD 450 has been melted using crucible furnace at 1500 ºC and poured into LFC mould at 1350-1400 °C. The measurement result of Carbon Equivalent (CE) meter shows Carbon value of 3.86% and Silicon by 1.86%. This measurement value is in accordance with the planned composition targets of 3.85-4% Carbon and Silicon 1.85-2%. This composition was included in the nodular cast iron FCD 450 which is widely produced in foundry industries. The average pouring speed for each sample was 13 seconds. Each casting product was cooled in room temperature and separated from the mould and then cut in accordance with each of the predefined pattern coating thickness variables.

III. Result and Discussion

A typical Fe–Si–Mg casting alloy FCD 450 was melt in an electrical furnace. Chemical composition of the nodular cast iron alloy is given completely on Table 1. Measurement of nodular cast iron composition were performed using a spectrometer test apparatus and a metal mold for rapid cooling.

TABLE I.
CHEMICAL COMPOSITION OF NODULAR CAST IRON FCD 450 (WT %)

Element	Fe	C	Si	Mn	P	S	Cr	Mo	Ni	Al
Amount (wt %)	92.08	3.86	2.17	0.438	0.085	0.005	0.024	0	0.909	0.033
	B	**Co**	**Cu**	**Mg**	**Nb**	**Pb**	**Sn**	**Ti**	**V**	**W**
	0.0005	0.038	0.189	0.073	0.004	0.0061	0.018	0	0.042	0.033

A. Influence of Coating Thickness on Surface Roughness of Cast Samples

Surface roughness of casting products is essential if the casting product is not machined on the surface. Figure 5 shows the effect of coating thickness and comparison of castings product of nodular cast iron FCD 450 using the lost foam casting. As can be seen, increasing the coating thickness affected the quality of casting products, which is agreement with the result of [11][8][12]. The coating thickness of 200 µm has the best casting integrity or quality compared to other coating thickness. Castings with a coating thickness of 200 µm provide an accuracy of size close to the size of the EPS pattern previously planned as shown Fig. 5 (b). Castings integrity and defects were checked by visual inspection. Surface roughness of all steps of the cast samples was measured using a portable roughness tester. The report of the surface roughness was measured at different location on sample. Surface roughness was measured by using SURFCOM 120A (Advanced Metrology System) profile meter.

The surface roughness indicator used was the average roughness value (Ra). The parameters of the roughness gauge was set: λc = 0.25 x 5 mm; Vv = 2K; Vh = 20. Measurements were made on each of the nodular cast iron thicknesses. Surface roughness measurements were made at three points on each thickness of the nodular cast iron. The effect of thickness of nodular cast iron castings on surface roughness in each thickness of the pattern layers can be seen in Figure 6. Figure 6 shows that surface roughness increases with increasing thickness of nodular cast iron FCD 450 cast sample. At thickness nodular cast iron of 24 mm, surface roughness cannot be measured due to casting defect. The surface roughness of casting product is influenced by several factors such as coating thickness, casting temperature, EPS density, sand grain size, pouring temperature, vibration, vacuum level and presence of carbon residue attached to cast iron surface [1][12].

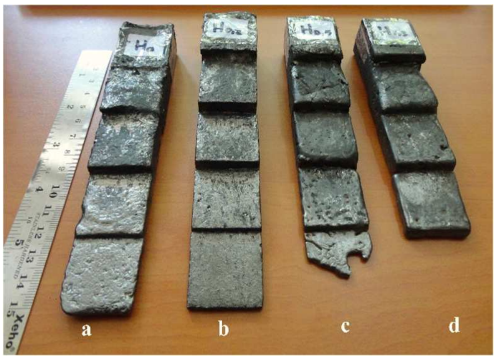


Fig. 5. Casting sample of nodular cast iron produced with different coating thickness variation of (a) 0 (without coating), (b) 200 µm, (c) 500 µm and (d) 1300 µm

The relationship between coating thickness to an average surface roughness of the nodular cast iron FCD 450 by using the lost foam method is shown in Fig. 7. The average surface roughness at coating thickness of 0 (without coating), 200, 500, and 1300 µm were 8.37, 5.85, 5.64, and 4.39 µm respectively. The average surface roughness of cast sample tends to decrease as the coating thickness of the EPS pattern increases. Surface roughness at 200 and 500 µm coating thickness did not decrease significantly.

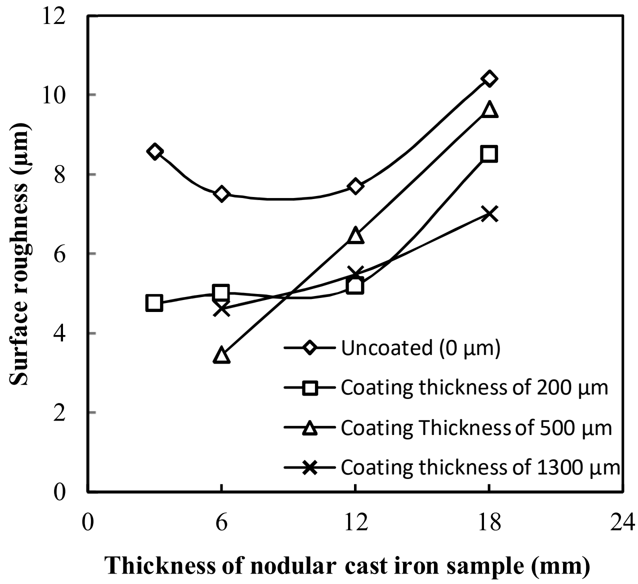


Fig. 6. Effect of nodular cast iron thickness and coating thickness on surface roughness of nodular cast iron FCD 450 sample.

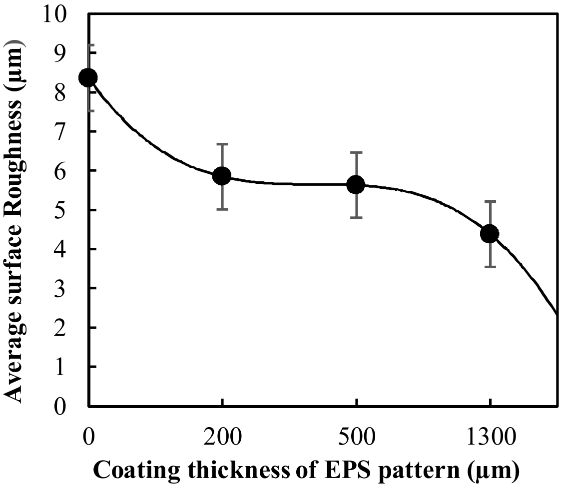


Fig. 7 Effect of coating thickness of EPS pattern on average surface roughness of nodular cast iron FCD 450

Uncoated patterns have highest surface roughness. This problem can probably be due to uncoated patterns will be in direct contact with the moulding sand. When the molten metal is poured into the mould, the molten metal will burn the EPS pattern and the molten metal will be in direct contact with the moulding sand. This causes the surface of the casting product to become rough because that are not coated with refractory material. Uncoated pattern will depend on the fineness of the moulding sand. Improving the fineness of the silica sand (mesh) will reduce the surface roughness of the castings [2,3]. The uncoated pattern will have a casting defect located near the inlet, this causes the surface of the casting product to become rough. This casting defects caused by the moulding sand that quickly fall apart before the molten metal solidifies. This causes the surface of cast sample become rough. The lowest surface roughness value (smooth) is owned by 1300 µm of EPS pattern coating thickness when compared to the other EPS coating thickness. When compared surface roughness of EPS 200 and 500 µm with 1300 µm, the 1300 µm pattern coating thickness would have a lower surface roughness but the casting product suffers from a cast defect on thinnest section of the castings (3 mm. The metal cannot fill up to a thickness of 3 mm. Figure 5 demonstrates the effect of coating thickness on the produced castings. As can be seen, increasing the coating thickness affected the quality of the casting and brought about misrun. This problem can probably be due to the back pressure developed in the cavity by the degradation of pattern, which was higher than the pressure exerted by the flowing metal front, thus retards the downward flow of the metal. This phenomenon slowed down the pattern evaporation process leading to misrun defect. Bottom filling approach was found to replicate only up to the 6 mm section thickness as observed in Fig. 5c, 5d [7]. Therefore, it is necessary to control the coating thickness that is most optimal for certain castings product thickness. Basically the surface roughness in this study is due to the quality of the EPS used. If the EPS used has a high density and there is not much porosity in the foam it will allow the casting product to be smoother. Surface roughness is highly dependent on the density and quality of the EPS used. Coating the pattern with refractory material does not completely make the surface of the casting product smooth. Based on experiments that have been done and the data obtained, it can be concluded that with the increase in coating thickness EPS patterns produce a surface roughness lower castings (smooth) on lost foam casting method.

B. Effect of Coating Thickness on Porosity

Porosity in this experiment is indicate as actual density of casting product. Porosity of nodular cast iron FCD 450 was measured using Archimedes principal law. The relationship between coating thickness of EPS pattern for each sample on actual density casting product can be seen in Fig. 8. Figure 8 shows that actual density of each casting product sample decreases with increasing coating thickness of the EPS pattern. The actual density of the casting sample that is higher shows the pores on the casting product will be less.

Increasing coating thickness a more rigid mould is obtained where coating material affects mould permeability. Therefore, the gas evolved and pressure developed from the degradation of the pattern could not escape freely through the sand grains thus developed a back pressure, which opposed the flow of the metal front [7]. When this happens, the reaction time increases and leads to an increase in the porosity trapped while casting process. In general, the mass density used for nodular cast iron at room temperature is 7.1 g/cm^3 [10]. The density is affected by the percentage of graphite carbon, with densities varying from 6.8 to 7.4 g/cm^3. Actual density of cast sample in coating thickness of 0 (without coating), 200, 500, and 1300 µm respectively is 7.011; 7.057; 7.026 and 7.001 gr/cm^3. Based on the test results that the actual density increases in the coating thickness pattern of 0 to 500 µm and decreases the actual density at 1300 µm thickness.

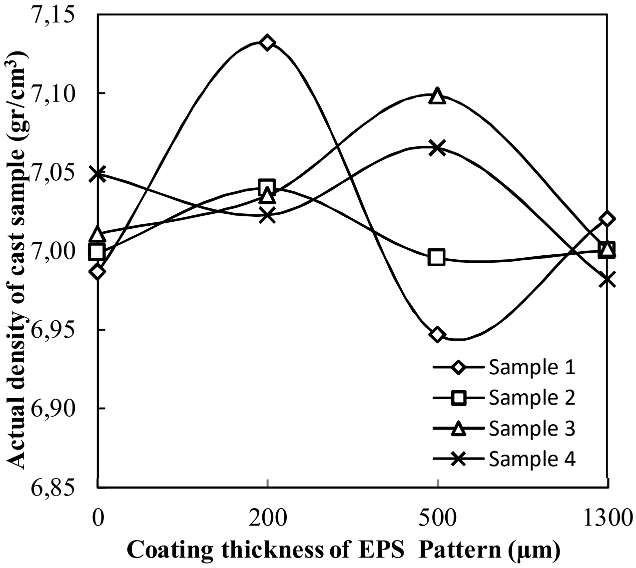


Fig. 8. The relationship between coating thickness of EPS pattern for each sample with actual density of nodular cast iron FCD 450

The highest actual density of EPS owned by coating thickness of 200 µm. This indicates that the pores found on the objects of the castings are getting smaller. This can be seen directly through visual observations as shown in Figure 4. Actual lowest density is owned by coating thickness of EPS 1300 µm. This is due to the decomposition of polystyrene gases trapped inside the metal fluid which is in agreement with the results of Karimian et al [3]. These gases are difficult to exit rapidly due to layers of EPS patterns coating that are too thick resulting in a lot of air being trapped. The more trapped gases in the molten metal will decrease the actual density of the casting material.

Figure 9 shows the relationship between coating thickness of EPS pattern on the porosity percentage of nodular cast iron FCD 450. The porosity increases with coating thickness of EPS pattern. The highest porosity percentage is owned by coating thickness EPS pattern of 1300 µm. Increasing the percentage of porosity in coating thickness of 1300 µm is powered by a decrease in the actual density of castings product. The decline in the actual density of cast sample indicate the level of porosity increases. The average percentage of porosity of casting product on coating thickness of 0 (without coating), 200, 500, and 1300 µm respectively was 0.026; 0.020; 0.024 and 0.028%. The lowest percentage of porosity is owned by coating thickness pattern of 200 µm. This is supported by a thin layer of coating material providing support for rapidly releasing exit gases from polystyrene decomposition through the gaps of the coating material and forwarded out through the mould sand.

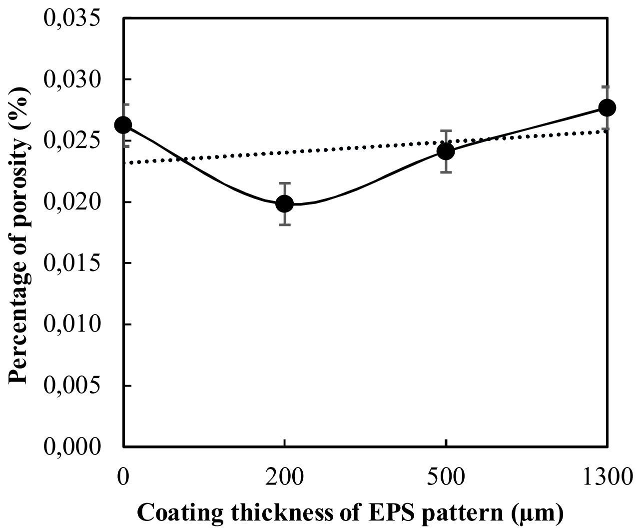


Fig. 9. The relationship between coating thickness of EPS pattern to percentage porosity of nodular cast iron FCD 450.

Porosity of casting product is influenced by the quality of EPS. If the EPS used as a pattern has enough pores it will support a high porosity in the castings. When examining the effect of coating thickness on a fraction of porosity region, it is necessary to calculate of density and thickness of EPS pattern, pouring temperature, metal stability, and the other parameters. Based on the experimental results and from data obtained it can be concluded that the porosity of nodular cast iron FCD 450 tend to increase with coating thickness of EPS pattern.

IV. Conclusion

From the experimental results showed the surface roughness decreases with increasing coating thickness of the EPS pattern. Uncoated patterns have highest surface roughness. Uncoated of EPS pattern influenced the casting integrity and quality. The coating thickness of 200 µm provides the highest actual density and the most accurate dimensions. Percentage porosity of nodular cast iron increased with increasing coating thickness of EPS pattern. Coating thickness EPS pattern of 1300 µm provides the highest percentage of porosity.

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