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# Influence of Sawdust Ash Addition on Molding Sand Properties and Quality of Iron Castings

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## Abstract

Sand molding casting has been widely used for a long time. But, one of its main drawbacks is that surface quality of the castings is not good enough for some applications. The purposes of this research were to investigate the effect of addition of sawdust ash of rubber wood (SARW) on molding sand properties and the surface quality of iron castings and to find an appropriate level of SARW with the appropriate properties of the iron castings. The molding sand compositions for making a sand mold consisted of the recycled molding sand, bentonite, water and SARW. The percentage levels of SARW were 0%, 0.1%, 0.2%, 0.3% and 0.4%. The different proportions of molding sand samples were investigated for the molding sand properties including permeability, compression strength and hardness. The results showed that addition of SARW had an effect on the molding sand properties. The appropriate percentage proportion of molding sand was obtained at 95.8% recycled molding sand, 0.8% bentonite, 3% water and 0.4% SARW. There were statistically significant differences of mean surface roughness and hardness values of the iron castings made from molding sand samples without SARW addition and the appropriate percentage proportion of molding sand. In addition, the average surface roughness value of the iron castings made from the sand mold with the appropriate percentage proportion of molding sand was ~40% lower than those of the iron castings made from molding sand samples without SARW addition.

**Keywords:** Sawdust ash, Rubber wood, Molding sand, Iron castings, Design of experiments

## 1 Introduction

Foundry industries are the main suppliers for producing castings supporting to a wide diversity of other industries such as automobile, agricultural machinery and machining tools. Sand casting has been widely used for over millennia and provided the foundation for the growth of a variety of industries. Quality of the sand castings is one of the most important aspects in guaranteeing the reliability of the products for delivering to the customers. However, one of its main drawbacks is that the surface quality of the castings is not good enough for some applications.

Generally, quality of the sand castings depends on the quality of molding sand. High quality of the castings can be desired if the molding sand has five quality characteristics consisting of strength, permeability, thermal stability, collapsibility and reusability. The strength of molding sand is the ability of the sand to sustain its shape whereas the permeability of molding sand is the ability of gas to escape through the sand. The thermal stability of molding sand is the ability of the sand to resist heat damage such as distortion and cracking. The collapsibility is one of the most important quality characteristics of the molding sand because it represents the ability of the sand to compress during solidification and collapse during the sand molding knockout. The last quality characteristic of molding sand is reusability which is the ability of the sand to be recycled for subsequent use [1].

Typically, there are many factors influencing the quality of castings during sand molding process and sand casting process. These factors include pattern design, molding material preparation,

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characteristics of sand mold and quality of raw materials. Moreover, addition of some materials with various fractions in the compositions of molding sand has impact on the properties of molding sand and quality of castings.

Puspitasari and Dika [1] investigated the effects of molding sand with different compositions of binder types (e.g., fly ash, mud, volcanic ash, tapioca flour, sago flour) on hardness, shear strength, tensile strength and permeability properties of green molding sand. They found that fly ash addition of 2% to the mould composition increased the hardness of the sand mould by 82.6%. The effect of molding sand composition on the green molding sand properties using Taguchi design of experiment was studied by Pulivarti and Birru [2]. They obtained the optimal green molding sand combination of fly ash 15%, molasses 2.25% and bentonite 8% and found that the additions of fly ash, molasses and bentonite can enhance the bonding strength of the sand mold and other properties. Meanwhile, other researchers reported that fly ash addition in molding sand can improve surface quality of steel castings [3], reduce defect of aluminum castings [4] and reduce total solidification time of the Al-ll% Si alloy castings [5]. Furthermore, fly ash was used as an additive material in other productions such as production of aluminum-matrix composites [6-8] and production of cements [9-11].

Apart from the fly ash, it was found that the addition of rice husk ash in the molding sand can increase compression strength and permeability of the molding sand and improve the surface roughness of the iron castings [12].

Like fly ash and rice husk ash, sawdust ash is an additive material effectively used for quality improvements of concrete [13-14], asphalt mixtures for rigid and flexible road pavement [15], black cotton soil [16-17]. Wood sawdust ash is the remainder obtained after burning wood sawdust in a fireplace or an industrial power plant [13]. Chowdhury et al. [14] stated that wood sawdust ash can be appropriately used to substitute for cement moderately in concrete production. It is an alternative cementitious material because the particles of wood sawdust ash can fill the voids between the bitumen contents and increase binding affinity to improve the performance of asphalt mixtures [15]. This is principally attributed to the higher pozzolanic affinity and the presence of fine and round particles of wood sawdust ash. They also stated that wood sawdust ash created a flat smooth surface which decreased the friction between the aggregates.

However, researchers have not yet used sawdust ash of rubber wood (SARW) as a component in molding sand. Thus, the research novelty is to investigate the effects of SARW addition on molding sand properties and surface quality of iron castings as well as to obtain an appropriate percentage level of SARW with the appropriate properties of the iron castings.

# 2 Methodology

## 2.1 Materials and procedure

Typically, the molding sand mixture consists of recycled molding sand, water and bentonite. In this study, the percentage composition of 95.8% recycled molding sand, 3% water and 1.2% bentonite was used as an experimental control of molding sand properties selected from the foundry experience. The SARW was used as an addition in the molding sand. It was supplied from the Gulf Yala Green Co., Ltd., Thailand. Fig. 1 illustrates typical SEM images of the SARW. Apparently, it showed that the particles have different shapes and geometries with nonuniform and porous textures.

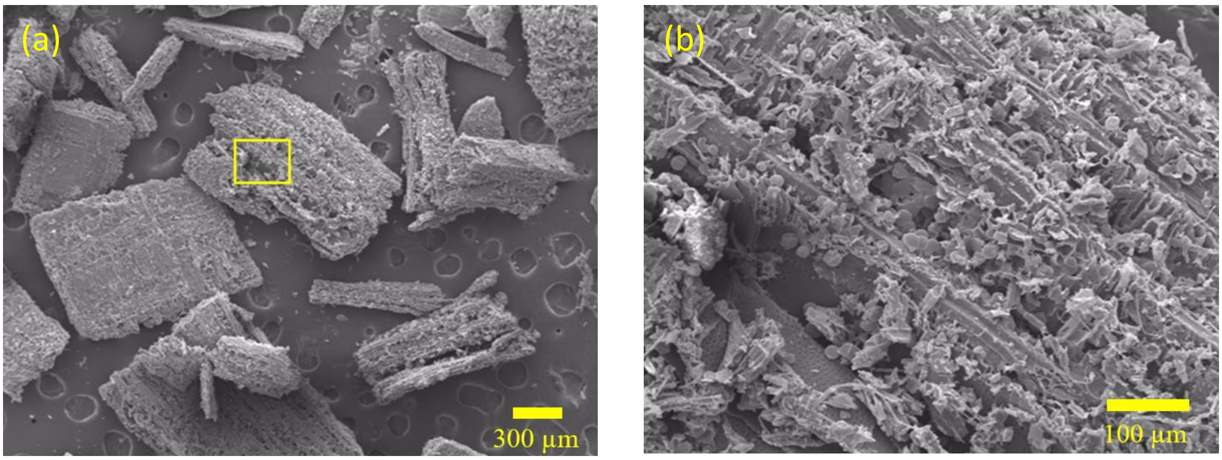


Fig. 1. Typical SEM images of SARW at (a) low (at 20x magnification) and (b) high (at 100x magnification)

Fig. 2 shows the experimental procedure. The proportional levels of SARW were 0.1%, 0.2%, 0.3% and 0.4%. The preparation of a specimen tube of molding sand was done based on the previous study [18]. The proportionate quantities of the recycled molding sand, bentonite, water and SARW were mixed in a muller, which was designed and fabricated in-house for laboratory use. The mixed sand was filled into a precision specimen tube to make American Foundrymen's Society (AFS) standard test samples. The mixed sand was compressed by dropping a 62.36 N sliding weight at a constant distance. All samples of the molding sand by varying the proportion of SARW from 0% (control sample) to 0.4% were prepared to be carried out for compression strength, hardness and permeability properties. Two samples of the molding sand were used to carry out the experiments for testing each of the molding sand properties. The green compression strength test of the samples was performed using a universal sand strength testing machine while the hardness test was done using a spring-loaded hardness tester with unit type B hardness tester for molding sand surface (g/mm$^2$). The permeability test was carried out using a calibrated permeability meter (Georg Fischer [+GF+]) with unit of A.F.S. permeability number.

The preparation of molten metal and the casting process were performed in a company located in Khon Kaen province, Thailand. The outside surface of each casting was examined by a stereomicroscope (SZX 9). The surface roughness (Ra) of a surface of each of the iron castings was measured by a surface roughness tester (Mitutoyo, Surftest 410) with the sampling and cut-off lengths for all roughness measurements of 32 and 8 mm, respectively. The Ra values were recorded at five distinct locations to avoid statistical bias of measurements. Averages from five observations were used for statistical analysis.

After solidification, each casting was machined on CNC milling machine (Micron VCE 750) to the test bar with 20 mm in width, 20 mm in length and 5 mm in thickness. Microhardness measurements were performed on the machined surface of the workpiece with a Vickers indenter under a load of 300 g applied for 10 s using a microhardness tester (Hollywood International Ltd., FM-800). Furthermore, the surface quality of the iron casting was examined by scanning electron microscope (SEM, Hitachi, SU-8030) at an accelerating voltage of 20 kV.

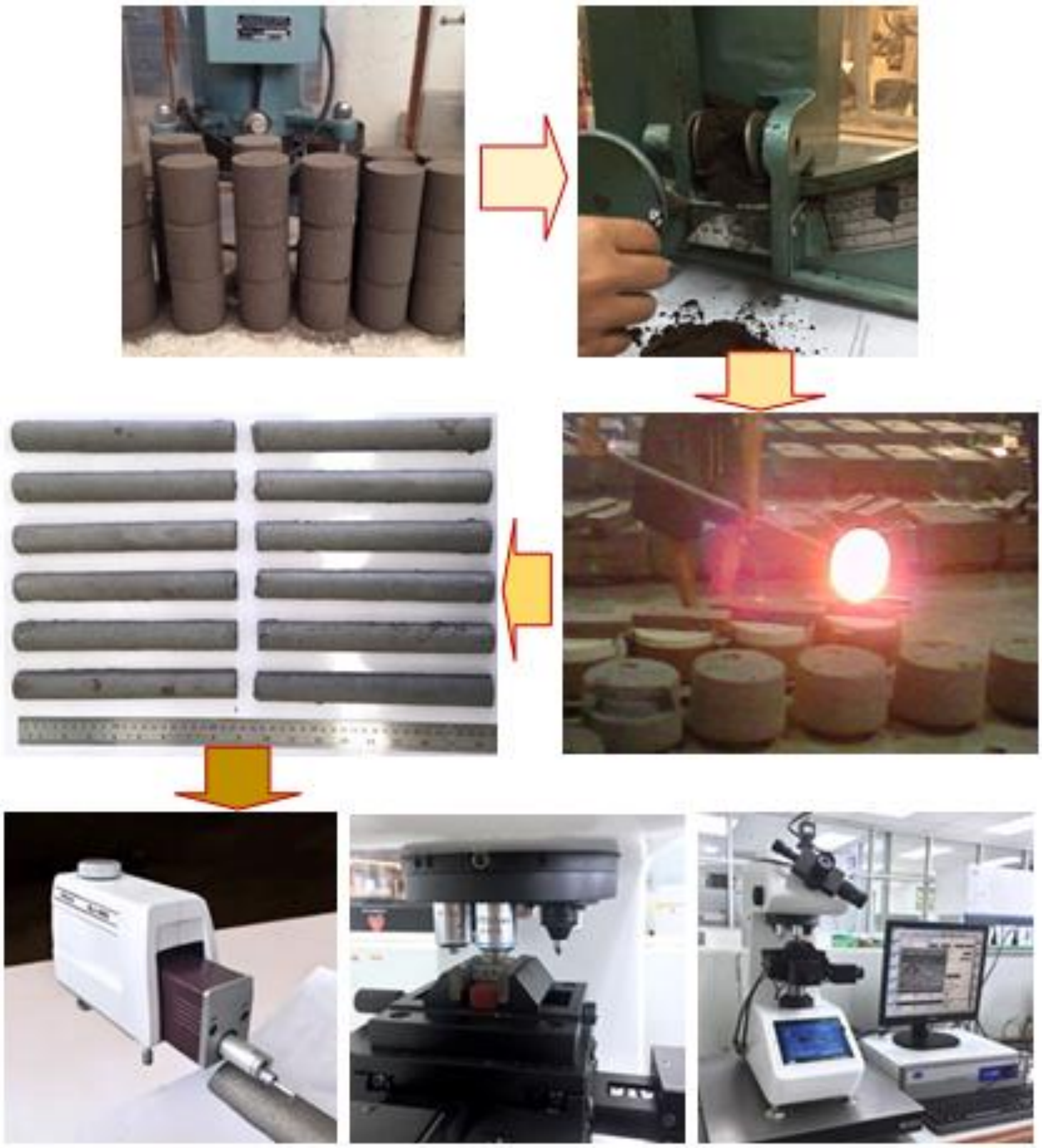


Fig. 2. Experimental procedure

## 2.2 Experimental design

Since casting process for carrying out all experiments could not be done within one day due to the peak times of the customers' demands, the experimenters planned to conduct the first replication for all levels of the proportion of SARW on the first day. Likewise, the second replication was planned to carry out the experiments on the second day. The experimenters also suspected that there might be significant day-to-day variation due to manufacturing variation at the molding sand preparation, natural variations in the materials, experience and skill of different workers. Therefore, they decided to investigate the effect of SARW on the properties of iron castings using a randomized complete block design (RCBD) considering days as blocks. The block (or the days for carrying out the experiments) formed a more homogeneous experimental unit on which to compare the effect of different proportions of SARW. The block design strategy can improve the accuracy of the Ra and hardness mean comparisons among the proportions by eliminating the variability among the different days.

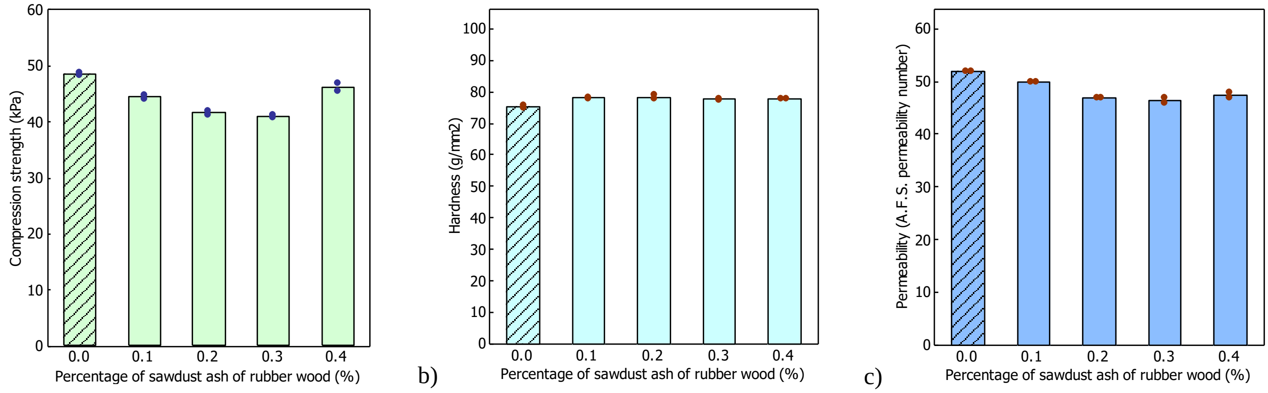
Before performing statistical analysis of the data, it is essential to make sure that the quality characteristics being studied is in fact normally distributed. The interpretations of the statistical analysis results would be misleading if non-normal data are analyzed as if they were normal [19]. The normality of the data can be tested through the probability plot [20]. The Anderson-Darling (AD) method is used for normality testing based on a hypothesis testing with the null hypothesis stating that the data are normal and the alternate hypothesis stating that the data are not normal. Normality also can be tested by quantile-quantile plot (QQ plot) [21].

Likewise, the validity of the assumptions must be checked before performing ANOVA [20]. The assumptions are based on the differences between the observations and the predictions that are called errors. The errors are normally and independently distributed with mean zero and constant but unknown variance. If the assumptions are valid, the ANOVA procedure can be used for further analysis. Violations of the assumptions and model adequacy can be easily investigated by the examination of residuals. The residual is defined from the difference between an observation and an estimate of the corresponding observation. A check of the normality assumption can be checked by plotting a normal probability plot of residuals for the randomized block design. If the normality assumption on the errors is satisfied, the plot resembles a straight line. The independence assumption on the errors can be checked by plotting the residuals versus run order or time. If the statistical model is adequate, the residuals must be structureless. The assumption of constant variance can be examined by plotting the residuals and the fitted (predicted) values. If the assumption of constant variance is violated, the plot looks like an outward-opening funnel or megaphone.

# 3 Results and discussion

## 3.1 Effect of SARW addition on molding sand properties

Fig. 3 shows the measured compression strength, hardness and permeability values of the molding sand with different proportions of SARW. Fig. 3(a) shows that the compression strength for the molding sand samples without SARW addition was higher than those for the molding sand samples with different proportions of SARW. Apparently, the molding sand samples without SARW addition exhibited the lowest hardness while the other molding sand samples with different proportions of SARW exhibited higher hardness as displayed in Fig. 3(b). On the other hand, Fig. 3(c) illustrates the permeability for the molding sand samples without SARW addition was higher than those for the molding sand samples with different proportions of SARW.



a) b) c)

Fig. 3. Variations in (a) compression strength, (b) hardness and (c) permeability of the molding sand samples without the SARW addition and with the different percentage proportions of SARW

The compression strength, hardness and permeability data sets were tested for normality by the Anderson-Darling (AD) normality test. Fig. 4 shows the probability plots for compression strength, hardness and permeability of the molding sand data sets. From Minitab software outputs, all *p*-values for normality testing using the AD method were greater than 0.05. These indicated that the data were normally distributed for a confidence interval of 95%.

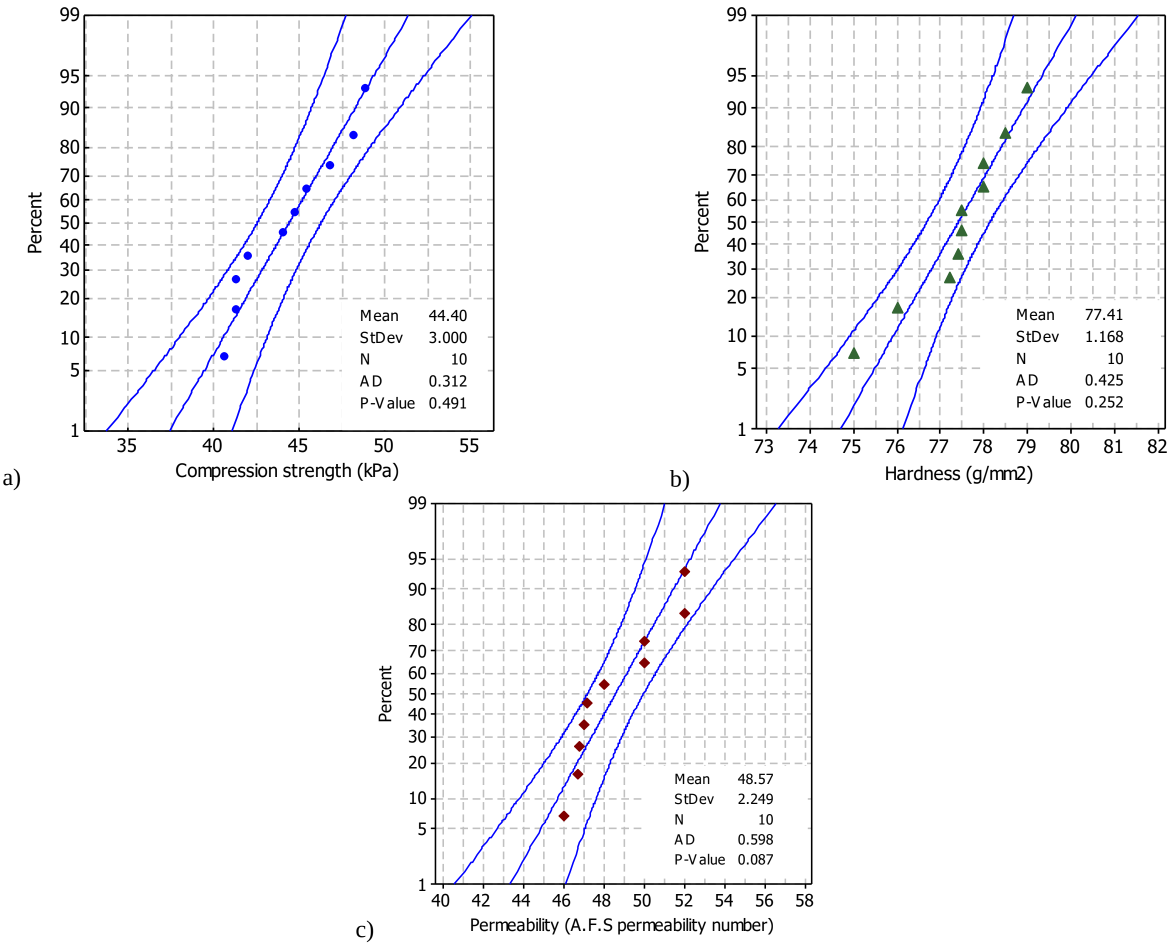



Fig. 4. Normality tests for (a) compression strength, (b) hardness and (c) permeability of the molding sand data

Based on the results of a one-way ANOVA, it was found that the *p*-values for compression strength, hardness and permeability were found to be less than 0.05. In addition, Table 1 presents the values of the determination coefficient ($R^2$) and the values of the adjusted determination coefficient (adj $R^2$) for the green molding sand properties. All values were high confirming the high significance of the completely randomized design. This indicated that SARW addition significantly affected the properties of the molding sand.

Table 1.
Results of ANOVA with *p*-values, $R^2$ and adjusted $R^2$ for green molding sand properties

| Green molding sand properties | *p*-value | $R^2$ | Adj $R^2$ |
|---|---|---|---|
| Compression strength | < 0.0001 | 0.9765 | 0.9577 |
| Hardness | 0.0095 | 0.9031 | 0.8256 |
| permeability | 0.0003 | 0.9775 | 0.9595 |

## 3.2. Effect of SARW addition on Ra of the iron castings

Fig. 5 shows the measured Ra values of the iron castings produced from the casting processes without SARW addition and with different proportions of SARW in the molding sand. It appeared that the iron castings produced from the casting processes without SARW addition had the highest Ra value, which was about as high as 25% those of the iron castings produced from the casting processes with the percentage proportion of SARW of 0.1% and 0.2%. The results also showed that the Ra values of the iron castings produced from the casting processes with the percentage proportion of SARW of 0.1% and 0.2% in the molding sand were considerably different due likely to the random variation of porosity and compositions at different locations on the surfaces of the iron castings. On the other hand, the Ra values of the two iron castings produced from the casting processes with the percentage proportion of SARW of 0.3% and 0.4% in the molding sand were not dramatically different. It was noted that the averages Ra of the iron castings produced from the casting processes with the proportion of SARW of 0.3% and 0.4% in the molding sand were

~40% higher than those of the iron castings produced from the casting processes without SARW addition. The observed Ra data were comparable with the related additive materials to the molding sand reported previously [18]. To examine and confirm the effect of proportion of SARW on Ra of the iron castings, ANOVA was employed.

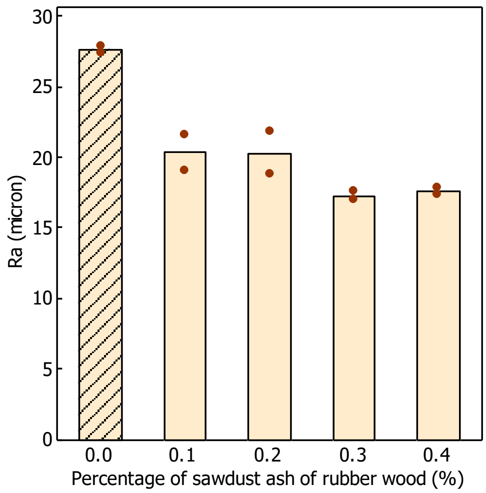



Fig. 5: Ra variations of the iron castings without SARW addition and with different percentage proportions of SARW

Before performing ANOVA, normality and model adequacy checking of the casting data were tested. Fig. 6 shows the probability plot for Ra of the castings data. The *p*-value for normality testing was greater than 0.05 and indicated that the data were normally distributed for a confidence interval of 95%. In addition, a normal probability plot of residuals of Ra data was tested for normality. There was no severe indication of nonnormality. The violation of independence of residuals was not existed because the residuals were structureless. There was no relationship between the size of residuals and the predicted values revealing nothing of unusual interest. The Ra data obtained from different days was homogeneous with less variability in Ra.

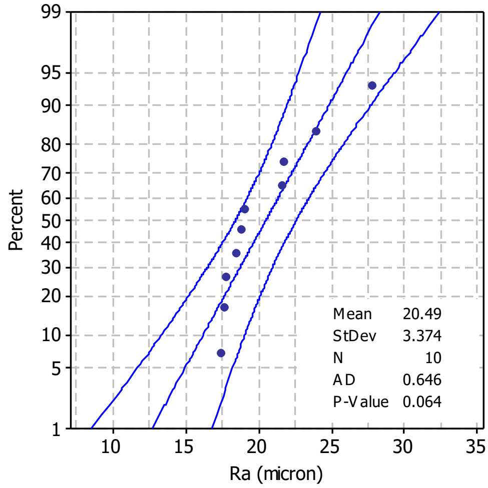



Fig. 6. Normality test for Ra of the castings data

The ANOVA for Ra of the iron castings is summarized in Table 2. The proportion of SARW mean square was many times larger than the error mean square and block mean square. It was noted that reducing the variability due to the days for carrying out the experiments decreased the experimental error. This also implied that pouring molten metal into sand mold samples on two different days of the experiments did not significantly affect the variability of Ra of the iron castings (*p*-value = 0.348) at the level of significance of 0.05. The *p* value of the effect of proportion of SARW was less than 0.05. This concluded that the proportion of SARW setting significantly affected the average Ra. In addition, $R^2$ and adjusted $R^2$ were very large indicating a reasonably high proportion of total variability explained by the model. Fig. 7 also confirms that the randomized complete block design model fitted the data set of Ra values and could accurately predict the values of Ra.

Table 2.
ANOVA for Ra of the iron castings

| Source of variation | Sum of squares | Degree of freedom | Mean square | *F*-value | *p*-value |
|---|---|---|---|---|---|
| Proportion of SARW | 140.02 | 4 | 35.01 | 22.55 | 0.005 |
| Block (day) | 1.76 | 1 | 1.76 | 1.13 | 0.348 |
| Error | 6.21 | 4 | 1.55 | | |
| Total | 147.98 | 9 | | | |

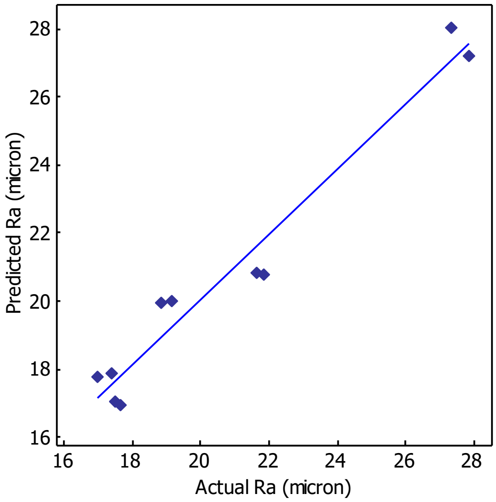


Fig. 7. Actual observations of Ra vs predicted values

## 3.3. Effect of SARW addition on hardness of the iron castings

The measured hardness values of the iron castings produced from the casting processes without SARW addition and with different proportions of SARW in the molding sand are illustrated in Fig. 8. Apparently, it showed that the iron castings produced from the casting processes without SARW addition exhibited the highest microhardness value, which was about as high as 10% those of the other castings. The hardness ranges were not markedly different between the iron castings produced from the casting processes with the proportion of SARW of 0.1% and that of 0.2% in the molding sand. Seemingly, the hardness values were not different between the two iron castings produced from the casting processes with the proportion of SARW of 0.3% and that of 0.4% in the molding sand samples.

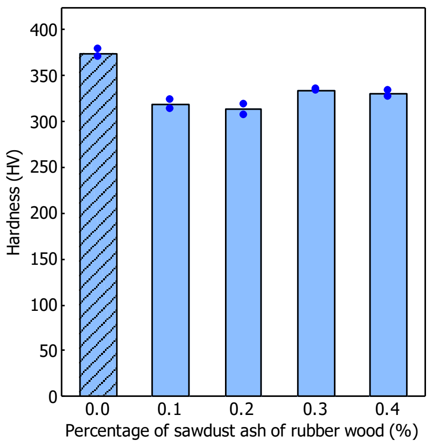


Fig. 8. Microhardness variations of the iron castings without SARW addition and with different percentage proportions of SARW

Fig. 9 shows the probability plot for hardness of the castings data. The *p*-value for normality testing was greater than 0.05 and indicated that the hardness data were normally distributed for a confidence interval of 95%. The model adequacy checking for the residuals of hardness data of the iron castings including the normality test, independence test, constant variance test and residuals vs block (day) revealed no severe indication and violation of nonnormality, independence of residuals and the relationship between the size of residuals and the predicted values. It also indicated that samples performed on different days were homogeneous with less variability in hardness.

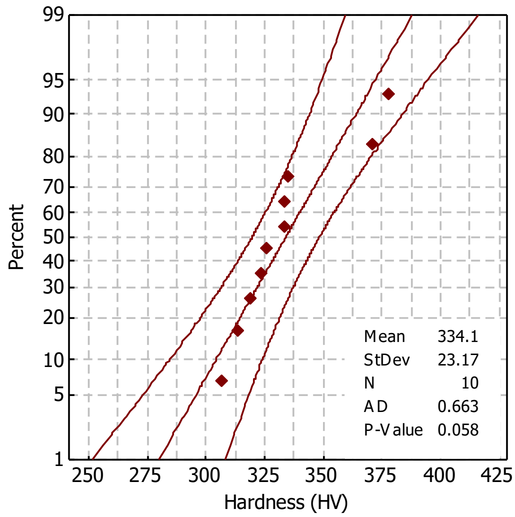


Fig. 9. Normality test for hardness of the castings data

Like the investigation of the effect of SARW addition on Ra of the iron castings, ANOVA was used to examine and confirm the effect of proportion of SARW on hardness of the iron castings as summarized in Table 3. The *p* value of the effect of performing casting process on different available time on different days was higher than 0.05. This implied that performing castings on different days did not significantly influence the variability of hardness of the castings. The *p* value of the effect of proportion of SARW on the average hardness of the iron castings was less than 0.05. The proportion of SARW setting significantly affected the mean hardness of the iron castings. It was unlikely that the hardness means were equal. The $R^2$ and adjusted $R^2$ were very high indicating a good fit and high statistical significance of the model with high proportion of total variability explained by the model. This verified that the randomized complete block design model fitted the data of hardness values and could accurately predict the values of hardness as depicted in Fig. 10.

Table 3.
ANOVA for hardness of the iron castings

| Source of variation | Sum of squares | Degree of freedom | Mean square | *F*-value | *p*-value |
|---|---|---|---|---|---|
| Proportion of SARW | 7034.89 | 4 | 1758.72 | 132.28 | < 0.0001 |
| Block (day) | 15.73 | 1 | 15.73 | 1.18 | 0.338 |
| Error | 53.18 | 4 | 13.30 | | |
| Total | 7103.80 | 9 | | | |

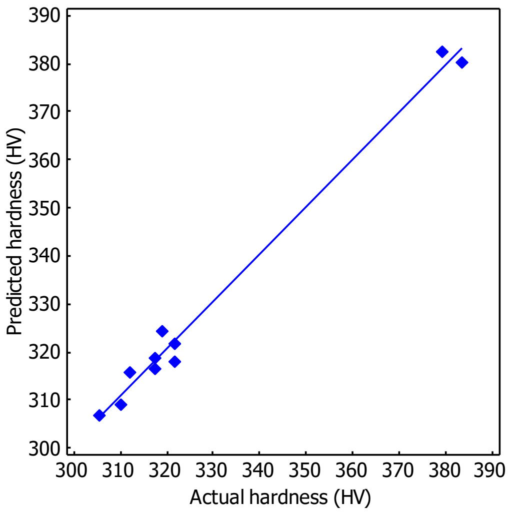


Fig. 10. Actual observations of hardness vs predicted values

## 3.4. Appropriate level of SARW on Ra and hardness of the iron castings

To identify the appropriate proportion of SARW with respect to minimization of Ra and maximization of hardness of the iron castings, a plot relationship between the Ra and hardness, and the proportion of SARW was prepared and is presented in Fig. 11.

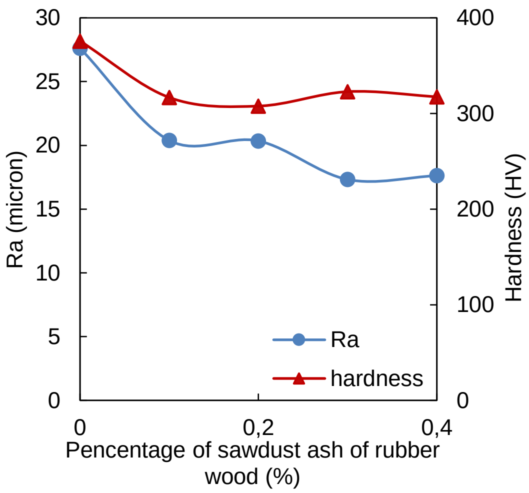


Fig. 11. A plot relationship between the Ra and hardness, and the proportion of SARW

The appropriate percentage proportion of SARW corresponds to the level with the lowest Ra and the highest hardness values. Although Fig. 11 is not easy to identify the appropriate percentage proportion of SARW, the level of 0.3% was selected with respect to the lowest Ra and the desired hardness values of the iron castings based on the hardness of iron castings in the range of manufacturer and customer specification (at least 200 HV). However, the level of 0.4% was also appropriate because the averages Ra and hardness were not apparently different between the levels of 0.3% and 0.4%. To confirm the appropriate level, the multiple comparisons test using the Fisher least significant difference (LSD) method was applied.

The procedure of LSD method uses the t-statistic for hypothesis testing, which is expressed as:

$$H_0: \mu_i - \mu_j = 0 \tag{1}$$

where $\mu_i$ and $\mu_j$ are the means of each of Ra and hardness values of the iron castings for the proportion of *i* and *j*, respectively. Assuming a two-sided alternative, the pair of means $\mu_i$ and $\mu_j$ would be declared significantly different if the expression of

$$\left|\bar{y}_{i.} - \bar{y}_{j.}\right| > LSD \tag{2}$$

with the quantity of *LSD* is defined as

$$LSD = t_{\frac{\alpha}{2},an-a}\sqrt{\frac{2MSE}{n}} \tag{3}$$

and *MSE* is the mean square error obtained from the ANOVA results [20]. If the expression (2) is correct, the means of each of Ra and hardness of the iron castings for the proportion of *i* and *j* significantly differ. The quantities of *LSD* for testing the comparisons of averages Ra and hardness were expressed in Equations (4) and (5), respectively.

$$LSD_{Ra} = t_{\left(\frac{0.05}{2}\right),[(5)(2)-5]}\sqrt{\frac{2(1.55)}{2}} = (2.571)(1.245) = 3.2 \tag{4}$$

$$LSD_{Hardness} = t_{\left(\frac{0.05}{2}\right),[(5)(2)-5]}\sqrt{\frac{2(13.3)}{2}} = (2.571)(3.65) = 9.38 \tag{5}$$

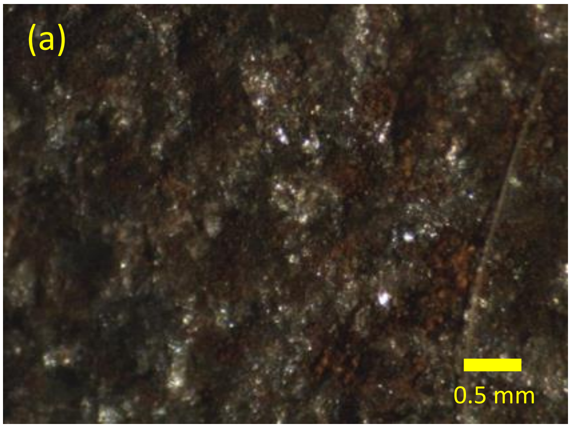
The results of the multiple comparisons of the averages Ra and hardness of the iron castings are shown in Table 4. The observed differences between each pair of averages Ra and hardness of the iron castings to the corresponding *LSD* were compared. The starred values indicated pairs of means that were significantly different at the level of significance of 0.05. Apparently, the averages Ra and hardness were not significantly different between the iron castings made from the molding sand samples with the SARW additions of 0.3% and 0.4%, respectively. However, the manufacturing cost of casting process would be reduced with the SARW addition of 0.4% due to the decrease of bentonite in the molding sand. Thus, the appropriate proportion of components was obtained at 95.8% recycled molding sand, 0.8% bentonite, 3% water, and 0.4% SARW.

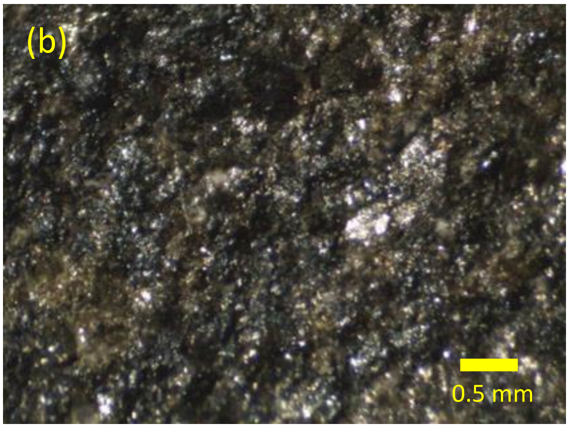
Table 4.
The multiple comparisons of averages Ra and hardness of the iron castings

| Comparing pairs | Ra $\lvert\bar{y}_{i.} - \bar{y}_{j.}\rvert$ | Hardness $\lvert\bar{y}_{i.} - \bar{y}_{j.}\rvert$ |
|---|---|---|
| 0 vs 0.1 | \|27.62 – 20.39\| = 7.23* | \|375.82 – 316.79\| = 59.03* |
| 0 vs 0.2 | \|27.62 – 20.35\| = 7.27* | \|375.82 – 307.77\| = 68.05* |
| 0 vs 0.3 | \|27.62 – 17.33\| = 10.29* | \|375.82 – 322.85\| = 52.97* |
| 0 vs 0.4 | \|27.62 – 17.63\| = 9.99* | \|375.82 – 317.48\| = 58.34* |
| 0.1 vs 0.2 | \|20.39 – 20.35\| = 0.04 | \|316.79 – 307.77\| = 9.01 |
| 0.1 vs 0.3 | \|20.39 – 17.33\| = 3.07 | \|316.79 – 322.85\| = 6.07 |
| 0.1 vs 0.4 | \|20.39 – 17.63\| = 2.77 | \|316.79 – 317.48\| = 0.69 |
| 0.2 vs 0.3 | \|20.35 – 17.33\| = 3.02 | \|307.77 – 322.85\| = 15.08* |
| 0.2 vs 0.4 | \|20.35 – 17.63\| = 2.72 | \|307.77 – 317.48\| = 9.71* |
| 0.3 vs 0.4 | \|17.33 – 17.63\| = 0.30 | \|322.85 – 317.48\| = 5.37 |

## 3.5 Surface quality examination of the iron castings

Fig. 12 shows stereomicroscopy images of outside surfaces of iron castings obtained from the company and the molding sand samples with the different percentage proportions of SARW before surface machining. The outside surface of the iron castings exhibited topographically rough protrusion and surface porosities observed under stereomicroscope. The reason behind this was the fact that molten metal poured into the sand mold and caused sand expansion [18]. However, the outside surfaces of the iron castings obtained from the molding sand samples with percentage proportion of 0.3% and 0.4% SARW (Figs. 12(e) and 12(f)) were smoother than other iron castings. The observed outside surfaces of the iron castings obtained from the molding sand samples with the proportion of 0.3% and 0.4% SARW were corresponding to the results from ANOVA and the LSD multiple comparisons (Tables 2 and 4, respectively).



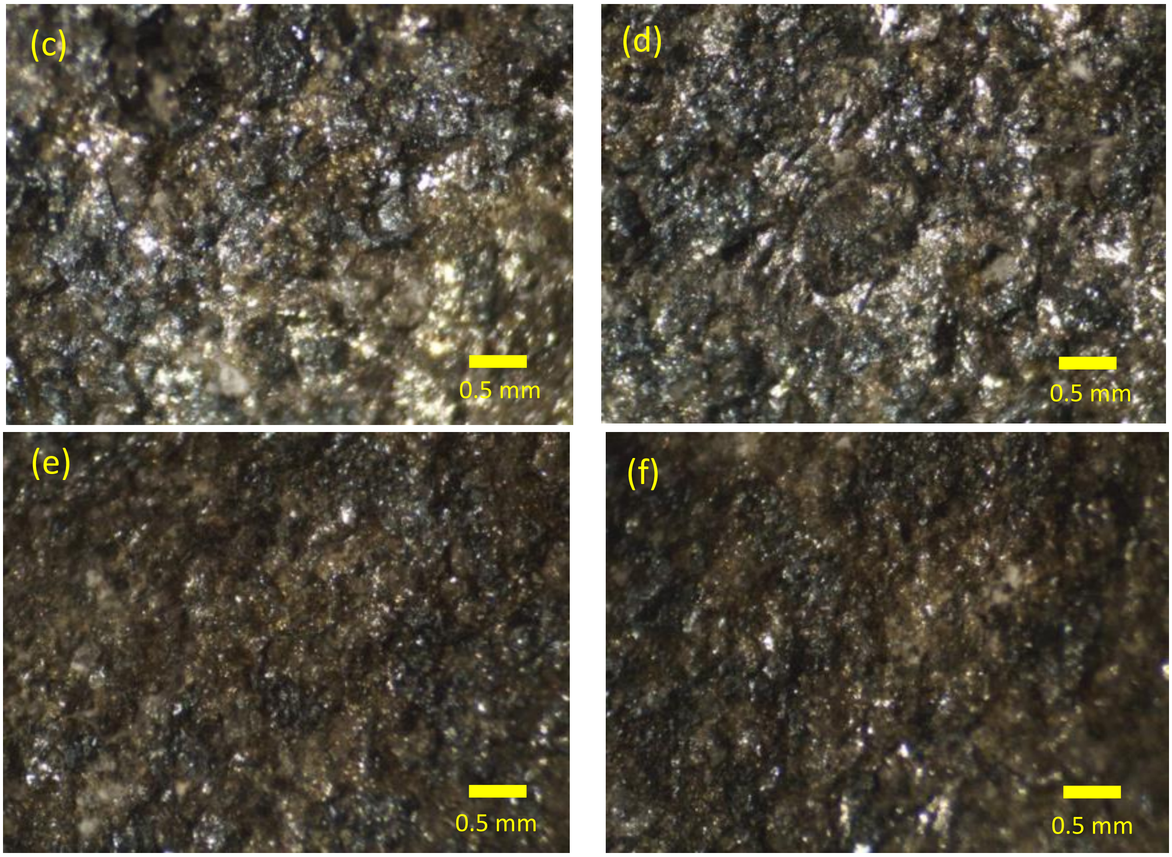



Fig. 12. Stereomicroscopy images of outside surfaces of iron castings (at 4x magnification) obtained from (a) the company, (b) the molding sand samples with the different percentage proportions of SARW of 0%, (c) 0.1%, (d) 0.2%, (e) 0.3% and (f) 0.4%

Fig. 13 shows typical SEM images of surface finish of the castings. Overall, the SEM images showed that the surface finish was similar between the iron castings obtained from the company's molding sand samples and those obtained from the molding sand samples without SARW addition. In both samples, there were holes and large porosities with different sizes and geometries as seen in Figs. 13(a) and 13(b). On the other hand, the surface finish was much better when the SARW was added in the molding sand as observed in Figs. 13(c)-13(f). However, there was a smaller number of large porosities found on the surface finish of the iron castings obtained from the molding sand samples with the SARW additions of 0.3% and 0.4%. The results indicated that the SARW addition to the molding sand had higher impact on the surface finish of the iron castings.

Gas porosity is a type of small defect that forms from bubbles within the casting after it is cooled [22]. The gas forms bubble within the casting. This is due to the fact that molten metal can hold a large amount of dissolved gas while the solid form of the same casting cannot hold it [23]. Gas porosity trapped inside the casting can lead to a high risk of metal failure and a sign of metal weakness. In addition, the defect in iron casting is a main risk to the foundry's reputation with their customers [24].

Like fly ash as an additive material in molding sand, SARW possibly resists the high temperature of the molten metal. It probably absorbs and transfers heat during pouring molten metal into the sand mold due to adequate permeability to effectively allow gases pass between the particles without generating casting defects. According to Fig. 13, there was a significant reduction of the size of gas porosity while the SARW addition was increased. This confirmed that the surface quality of the iron castings was improved leading to product quality improvement.

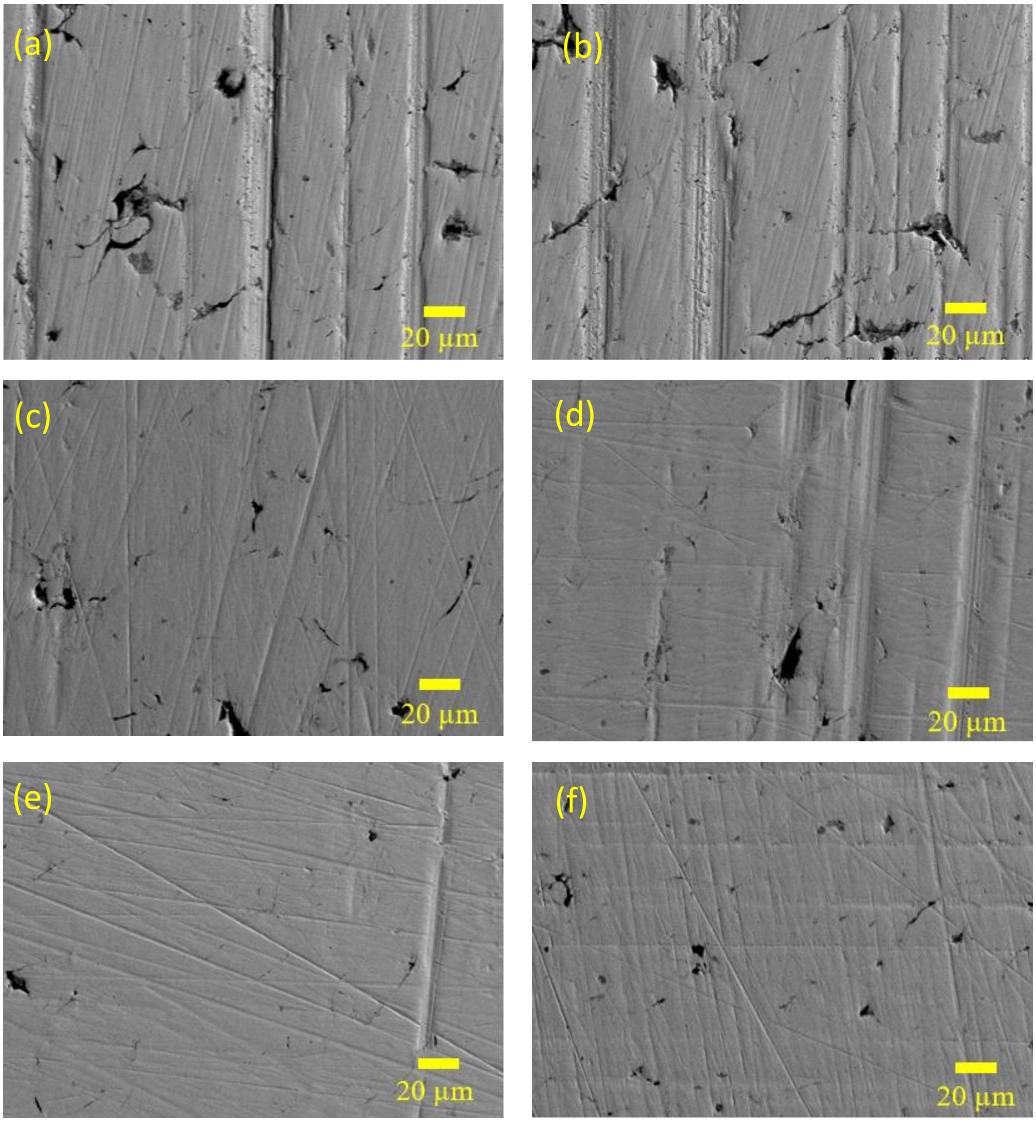



Fig. 13. SEM images of surface finish of iron castings (at 500x magnification) after machining obtained from (a) the company, (b) the molding sand samples with different percentage proportions of SARW of 0%, (c) 0.1%, (d) 0.2%, (e) 0.3% and (f) 0.4%

## 4. Conclusions

This novel research study has not only investigated the effect of addition of sawdust ash of rubber wood on the molding sand properties and surface quality of cast iron but also has obtained an appropriate percentage level of sawdust ash of rubber wood with the appropriate properties of the iron castings including hardness and surface roughness. In addition, this research contributed to the comparative performance study of the five molding sand proportions and the castings using randomized complete block design coupled with analysis of variance and obtaining the appropriate level of sawdust ash of rubber wood using the least significant difference test. Based on the findings of this research, the following conclusions could be drawn:

- The SARW addition significantly affected the properties of the molding sand including compression strength, hardness and permeability at the significance level of 0.05.
- The pouring molten metal into sand mold samples on two different days of the experiments did not significantly influence the variabilities of surface roughness and hardness of the castings.
- The appropriate proportion of molding sand components was obtained at 95.8% recycled molding sand, 0.8% bentonite, 3% water and 0.4% SARW.
- The outside surface of the iron castings made from the sand mold with the appropriate percentage proportion of molding sand had ~40% Ra lower than that of the iron castings made from sand mold samples without SARW addition.

- The average hardness value of the surface finish of the iron castings made from the sand mold with the appropriate percentage proportion of molding sand was slightly lower than that of the iron castings made from sand mold samples without the SARW addition with the specific range of the particular manufacturers' products.
- The number of large porosities on the surface finish of the iron castings was decreased with the SARW addition to the molding sand.

## Conflict of Interest

The authors declare that they have no conflict of interest.

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