Cost of Quality Optimization in Sand Casting Operations

S Alfarisi¹, Akh. Sokhibi² and Mia Ajeng Alifiana
¹,² Department of Industrial Engineering, Universitas Muria Kudus, Indonesia
³ Department of Management, Universitas Muria Kudus, Indonesia

Abstract. Sand casting is one of the oldest methods applied in foundries industry. However, this method has several disadvantages such as high consumptions of energy. It has an impact on total cost production per pieces. In other side, the problem of cost of quality need an appropriate approach to reduce this cost immediately. This study proposed the alternative sand casting process, CRIMSON (Constrained Rapid Induction Melting Single Shot Up-Casting), to investigate the differences between this methods. The result of this study was indicate clearly that CRIMSON sand casting has a lower total cost per pieces which is the result of lower energy consumption and no cost in sortation and rework because the process was in statistical control.

1. Introduction
Many different factor and variables need to be considered to making a product. For example, in sand casting operations, the desirable characteristic of light weight, resistance to corrosion and strength [1]. In sand casting operations, there are many parameters to be involved in a process, such as melting temperatures, pouring speed, composition, micro structure, size of sand and solidification time [2][3][4][5][6]. These parameters need to be considered properly to produce the best quality product because the business competition has more competitive and a firm level competition has moved to global competition [7][8][9]. But, even in fully controlled process, casting operation are uncertainty which challenges explanation about the cause of defect [10]. previous researcher mentioned that casting defects can be minimized by taking corrective action in pattern, mould making, core making and melting process [11][12]. Khan and Mughal [13] found that the two consecutive stages in casting are solidification and filling process where this technique is imperative for upgrading the productivity as well as lessens the manufacturing cost by minimizing the rejection rate.

Taguchi Loss Quality is one of the most powerful approaches to design a high quality systems [14]. The cost of quality is not the cost of creating a quality product but its refer to the cost of not creating a quality product or service [15]. One of the most effective optimization processes is the taguchi method. Taguchi’s quality loss of function is based on this loss assessment by using the square deviation of the quality characteristic with respect to its nominal value, which is considered as target value [16]. Quality Loss Function has found it specific use in the fields such as tolerance, design optimization and production economics [17][18]. Quality loss function of Taguchi deals with the effect of a performance variation.

The objective of this study is to investigate the best expected cost for alternative manufacturing process in sand casting operations. This study proposed an optimal solution to reduce the cost of loss quality in sand casting manufacturing. In this study, the product produced from sand casting operations is intake manifold. The problem is the diameter of the pipe, where the tolerance of diameter is 30 ± 0.2 mm.
2. Methodology

Quality loss function of taguchi approach actually describe the cost arise between the gap of conformance in certain quality characteristic of product [19][20][21][22]. In this case, the tolerance means the deviation of the target. The equation of loss \( L(y) \) can be formulated as shown in equation 1

\[
L(x) = k(x - N)^2
\]  

(1)

where \( L(x) \) = loss function, \( k \) = constant of proportionality, \( x \) = the quality characteristic of interest and \( N \) = its nominal value. The amount of “k” can be formulated by using equation 2.

\[
k = \frac{L_c}{Tol^2}
\]  

(2)

where \( L_c \) = Consumer loss or cost of rejects when parts is out of tolerance, and \( Tol \) = Tolerance of measured value of quality characteristic (in case of nominal is the best).

The proposed problem in this case was the pipe diameter in intake manifold which the target was 30 mm as shown in figure 1. The tolerance of this pipe diameter was 0.2 mm. by using equation 1, the loss cost could be obtained. Then, the lost function could be figured into production piece cost computation. The total piece cost can be obtained by using equation 3.

\[
C_{pc} = C_p + C_s + qC_r + L(x)
\]  

(3)

where, \( C_{pc} \) = total cost per pieces, \( C_p \) = production cost per piece, \( C_s \) = inspection and sortation cost per piece, \( q \) = proportion of parts falling outside of the tolerance limit and needing rework, \( C_r \) = rework cost per piece for those part requiring rework, and \( L(x) \) = taguchi loss function per piece. The result of cost per pieces can be used to find the expected cost of several alternative in sand casting process to find the minimum cost of productions. To calculate the expected values of taguchi loss function, the formulation was given by equation 4.

\[
E[L(x)] = k(\sigma)^2
\]  

(4)
where $\sigma^2$ = the variance of the production process and its square root is the standard deviation $\sigma$ of the process. The properties of comparison of sand casting has been setup. The scenario of lost function used in this study was nominal is the best. The lost will occur when a product’s functional characteristic differs from its nominal or target value [23].

3. Result and Discussion
The calculation of taguchi loss function was started by estimated the constant $k$ value. In this case, the specified dimension of intake manifold pipe was 30 $\pm$ 0.2 mm. Based on the investigation for 100 sample product, there was found 40% product will be returned of repair, where the repairation cost was $10. The expected cost of the repair was calculated as follows:

$$E[L(x)] = 0.4($10) + 0.6(0) = $4$$
then,

$$4 = k(0.2)^2$$
$$k = \frac{4}{0.04} = $100$$

So, the taguchi loss function in this case was the following:

$$L(x) = 100(x - N)^2$$
$$L(x) = 100(0.2)^2 = $4$$

it was mean that the cost of lost quality per pieces was $4. This loss cost was caused by the different conformance quality of product. Because the high cost of loss quality, then this study proposed alternative tolerance to estimate the minimum cost of quality. The first tolerance proposed was 0.1 mm and the second was 0.05 mm. refer to equation 1, for a tolerance of $\pm$ 0.1 mm, the value of the loss function was

$$L(x) = 100(0.1)^2 = $1$$
and for a tolerance of $\pm$ 0.05 mm, the value of loss function was

$$L(x) = 100(0.05)^2 = $0.25$$

by setup the tolerance in $\pm$ 0.05 mm, the cost of loss quality was lower than $\pm$ 0.2 mm and $\pm$0.1 mm. However the reduction of tolerance must be followed by the better production procedures. Then, the following step was investigated the cost of production per pieces by using the different process. The different process proposed here was sand casting process by using CRIMSON (Constrained Rapid Induction Melting Single Shot Up-Casting) method and conventional sand casting method. This two method has been classified the properties cost in production process as shown in table 1.

| Cost Properties                  | CRIMSON Sand Casting | Conventional Sand Casting |
|----------------------------------|----------------------|--------------------------|
| Production cost per piece        | $5                   | $9                       |
| Cost of sortation per piece      | $0.5                 | $0.5                     |
| Rework cost per piece (only if tolerance exceeded) | $15                  | $15                      |
| Taguchi loss function            | Equation 1           | Equation 1               |
| Process standard deviation       | 0.04                 | 0.09                     |

The total cost per pieces including all of the properties cost as shown in table 1. By calculating the cost of properties, the cost per pieces can be obtained to find the cost different between two different process. For the cost of rework in both in CRIMSON sand casting and conventional sand casting was only applicable to those parts the fall outside the specified tolerance of $\pm$ 0.2 mm. The proportion of parts falling outside of the tolerance limits ($q$) was found by using the standard normal $z$ statistic. For the CRIMSON sand casting, the $z$-value was $0.2/0.04 = 5$. The probability was out of the $z$-value where its
meant there were virtually no out of tolerance unit produced. The taguchi loss function was given in equation 4. By using equation 4, the expected taguchi loss function cost was obtained as follows:

$$E[L(x)] = 100(0.04)^2 = \$0.16,$$

then the total cost per pieces for CRIMSON sand casting was calculated by equation 3, as follows:

$$C_{pc} = 5 + 0 + 0.16 = \$5.16$$

per pieces. The advantage of this fact that there were no cost of sortation and cost of rework because the process was in statistical control.

For the conventional sand casting, the z-value was $0.2/0.09=0.013209$. The expected taguchi lost function was shown as follows:

$$E[L(x)] = 100(0.08)^2 = \$0.64,$$

the total cost of conventional sand casting was calculated as follows:

$$C_{pc} = 9 + 0.5 + 0.013209(15) + 0.64 = \$10.338$$

Based on the comparison result of the CRIMSON sand casting and conventional sand casting, especially in context of total cost per pieces, the CRIMSON process has the lower cost per pieces. This result actually has been predicted because in some research mentioned that the consumption energy in CRIMSON sand casting was lower about 50% than conventional sand casting.

4. Managerial Implication
The most contribution of this research for decision maker was the CRIMSON sand casting process was better to upgrading the quality of product as well as lessen the cost of rejection. The decision maker have to give more attention in quality because it has a significance correlation with production cost. The better production process, means the process was in statistical control, will eliminate a rework cost which is contribute to the total cost per pieces. Using CRIMSON sand casting, the sand casting operations was more stable and controllable than using conventional sand casting process.

5. Conclusion
The quality loss function of taguchi was indicate as powerful approach to determine the best alternative and process in manufacturing process. In case of intake manifold production, this study has obtained that the CRIMSON sand casting has a better quality loss function which is correlated with the total cost per pieces. Actually, this result has been predicted because based on previous study has mentioned that the CRIMSON sand casting has more efficient energy consumption. As energy intensive industry, the efficiency of energy has a significant impact in the process as well as in the financial aspect. So, this result strengthen the previous study and also indicate the prove that the efficiency in energy and material consumption has a strong correlation to the total cost per pieces. However, this study will be more integrated if this study involving a complex taguchi method, such as design of experiment to find the best parameters independent to increase the quality by using orthogonal array.

6. References
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