COST REDUCTION IN MANUFACTURING OF COUNTER WEIGHT AND ITS MATHEMATICAL CALCULATION METHOD

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ABSTRACT

The increasing demand on heavy equipment for development purposes is enforcing manufacturer of construction machinery to improve the efficiency of usage of steel scrap. Excavator as one of heavy equipment is designed and accomplished with counter weight at its backside to keep a balance condition during its operation. The counter weight itself is filled with the mixing of steel scrap and concrete such that achieving required weight. The shortage of steel scrap which also followed with its increasing price leads to find out the alternative solutions. The utilization of other materials such as brown iron ore, ferro-oxide, and steel sand to replace or reduce the number of steel scrap is described in this paper. At the previous stage, it is clearly understood that the density of those materials is significantly affecting to the reduction of steel scrap number and consequently contributing to cost reduction of manufacturing process. It was caused by the total volume of box of counter weight is remaining unchanged as well as its total weight. From a series of simulation and experimental result, the material FS-55, having density of 3.76 gr/cm³, showed the highest on the affordable cost reduction. Since the application of FS-55 as replacement material, a cost reduction of more than 30% compared with original cost was achieved. A mathematical model for optimizing the quantity of replacement material is introduced in this paper.

Key Words: Counter Weight, Steel Scrap, Steel Sand, Density, Cost Reduction

1. INTRODUCTION

Excavator is one type of heavy equipment which is widely used for construction. Therefore, it is classified to construction machinery equipment. Besides the engine, radiator, boom, arm, main frame, hydraulic unit and other mechanical parts, each design of excavator unit should be accomplished with a counter weight. The detail description could be found at Operation Manual of Excavator 2003 (a). This counter weight is put at the backside and meant to keep a balance condition during the operation of excavator. The main material and components used in excavator are comprised of steel-based materials which are expensive and can not be easily purchased. Sometimes, the materials should be imported from certain country.

In line with the emerging demand of steel materials, especially caused by the construction of facility and infrastructure for Summer Olympic 2008 in China and by the renewal and inquiry of ship building all over the world, the price of steel materials is significantly increasing since year 2004. Particularly, compared with the price in 3rd quarter 2007, the price in 3rd quarter 2008 is going up to more than 200%. This is a consequence related to the economic principle which best-known as the law of supply and demand (c) that firstly promoted by Adam Smith. Furthermore, the price of construction purposes steel-products such as concrete steel bar, H-beam, U-beam, and angle beam, is also much increasing since their base raw material is steel scrap. Although the portion of steel scrap for mill steel production is not as much as construction purposes one, however, the increasing price of hot roll steel plate which contributes as the highest portion of cost structure of excavator gives impact to various condition. This may cause to higher cost should be spent for supporting component as well as supporting material such as welding wire. It is relatively different from the selling price of automotives that can be adjusted from year to year as the new product or design is launched. Due to the number of excavators produced by manufacturer is much less than automotives and the cycle of model change for excavators is also significantly longer, the adjustment of selling price relatively difficult. To compensate the additional cost, therefore, the cost reduction activity has to be carried out. Togar (d) had presented the affordable cost reduction for the utilization of FS-55 as replacement material. To keep the sustainability of research, a mathematical model for optimizing the quantity of replacement material used for counter weight of excavator is introduced in this paper.
2. COST REDUCTION AND STRUCTURE OF COUNTER WEIGHT

Each company possesses vary activities to achieve its goal and to improve the performance of the company. Total quality management which is most frequently used in acronym as TQM is one of foundation for continuous improvement. It is described by James F. Cali (b) that cost reduction should be a part of TQM implementation, especially for the Department of Purchasing. Based on the handled business activity, term of Procurement Department is also used instead of Purchasing. Cost reduction is one of key factor to increase the profit and income of a company. For most of service and trading companies, the increasing of sales amount is the main action to obtain an utmost income. However, compared with business in the field of manufacturing, the cost reduction of raw material contributes much higher profit than increasing of sales amount since material cost is the main portion in manufacturing industries. Therefore, cost reduction is indispensable in each manufacturing industry. Various activity and efforts could be done to reduce material cost such as purchasing a same material with cheaper price from other supplier, review the product design to shorten material consumption, or replacement with a new material specification which can give a same level of quality. In this paper, the main activity to achieve the cost reduction is by replacement of material to be filled into counter weight of excavator.

The structure of box for counter weight is shown in Figure 1. This box is called as a counter weight when the materials have been filled into the box. The materials comprised of steel scrap, sand, and cement which are mixed as homogenous as possible in order to obtain the required total weight. The position of this counter weight after installed at the back side of excavator is shown in Figure 2.
3. RESEARCH METHOD

The original idea of this research was coming from the increasing price of steel scrap while Hitachi Construction Machinery can purchase the steel scrap in a relatively lower price than market price because the scrap is originated from the cutting components produced to fabricate the excavator unit. Another factor to pursue the research is the possibility of replacing the steel scrap with iron ore which can be purchased from local (domestic) and other country (import). In this case, a double profit is expected to be arising from the cheaper price of iron ore and from re-selling some portion of the continuously purchased steel scrap. The term of re-selling is used due to the main business of Hitachi Construction is not to sell the raw material but the finished or semi finished products.

Maintain the total weight of counter weight and rigidity of mixed material
First consideration to be encountered is to maintain the total weight of counter weight without any specific requirement of material filled inside. Then, the rigidity of the mixed materials by utilizing binding agent such as cement should be sufficiently strong to avoid shaking during operation of equipment. Since the volume of counter weight is constant for each model, and in order to keep the total weight remain unchanged, density of the mixed materials need to be in appropriate number. From the earlier stage of fabrication of excavator, the counter weight was originally filled with steel materials such as scrap or any other type of disposal steel. The emerging demand on steel materials leads to a higher recycle process of steel scrap at mill steel manufacturer side. It is a responsibility for procurement department and in collaborating with designer to find out other material which can replace or reduce this steel scrap. In this research, the fluctuating price of steel scrap is really utilized as a parameter to control the number of steel scrap to be used as a part of mixture composition filled in counter weight.

Calculate and summarize the composition of mixed material
The first step is to calculate and summarize the data related to the detail composition of steel scrap mixed with sand, water and cement as well as the density associated with this mixture for each model or type of excavator. There are several models of excavator designed and produced by Hitachi. Although the main parts such as engine, radiator, etc. are still imported from Japan, some of these models, especially for the unit weight up to 30 ton, have been fabricated and assembled in Indonesia. The main utilization of these models is for public work purpose, construction of infrastructure and road, forestry, etc. For unit weight from 45 ton up to the ultra large size whose weight could reach 800 ton is assembled in Japan where some of fabricated mechanical parts are carried out in Indonesia. The structure information for each model, consisting of total weight, box weight, volume of box, and density of material mixed inside the counter weight which produced in Indonesia is shown in Table 1. The total weight, box weight and volume are following the design result while the density is associated with the mixed materials. This design surely allows the fabricator to select and decide the mixture composition as long as the total weight is consistently maintained. The density shown in Table 1 is obtained based on the utilization of steel scrap, cement, water and sand as a mixture composition, where density is defined as the total mass of mixed materials that put inside the box divided by the volume.

<table>
<thead>
<tr>
<th>Model</th>
<th>Total Weight[Kg]</th>
<th>Box Weight[Kg]</th>
<th>Volume [Liter]</th>
<th>Density[g/cm3]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZX200-3Std</td>
<td>4350</td>
<td>326</td>
<td>1250</td>
<td>3.21</td>
</tr>
<tr>
<td>ZX200-3LC</td>
<td>5350</td>
<td>340</td>
<td>1250</td>
<td>4.01</td>
</tr>
<tr>
<td>ZX200-1Std</td>
<td>4250</td>
<td>306</td>
<td>1104</td>
<td>3.57</td>
</tr>
<tr>
<td>ZX200-1LC</td>
<td>5250</td>
<td>320</td>
<td>1104</td>
<td>4.47</td>
</tr>
<tr>
<td>ZX330-3Std</td>
<td>6800</td>
<td>481</td>
<td>1703</td>
<td>3.71</td>
</tr>
<tr>
<td>ZX330-2M</td>
<td>7400</td>
<td>481</td>
<td>1703</td>
<td>4.06</td>
</tr>
<tr>
<td>ZX110-1</td>
<td>1800</td>
<td>197</td>
<td>623</td>
<td>2.57</td>
</tr>
</tbody>
</table>
Utilization of replacement material
The second step is to replace the steel scrap each with brown iron ore (named as Local), steel sand-magna dense (named as Import), ferro-oxide (named by FS-55), respectively and mix up with cement and water in order to obtain the composition of mixture with density for each model shown in Table 1. The experiment should be carried out repeatedly and varying because the materials are not in a fix or constant structure or shape and there is no defined mathematical formula to determine their exact weight. One example of this mixing variation carried out for the counter weight of ZX210-Std model is shown in Table 2. Just for simplification purpose of name, mixture of cement and water is called as concrete. The original is stand for mixture composition consisting of steel scrap, cement, water and sand. It is clearly shown that the weight of each material necessary to achieve the total weight is varied. Furthermore, in order to maintain the total weight, it is understood that the steel scrap can not be totally replaced but reduced. The images of steel scrap, Import-steel sand, ferro-oxide FS-55, and Local- brown iron ore are depicted by Figures 3a, 3b, 3c, and 3d, respectively. Figures 3 express that the shape or structure of materials is not constant nor fix in size.

Table 2. Various Mixture Composition of Counter Weight for ZX200-1Std

<table>
<thead>
<tr>
<th>Component</th>
<th>Original [Kg]</th>
<th>Import [Kg]</th>
<th>Local [Kg]</th>
<th>FS-55 [Kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box</td>
<td>306</td>
<td>306</td>
<td>306</td>
<td>306</td>
</tr>
<tr>
<td>Steel Scrap</td>
<td>2550</td>
<td>200</td>
<td>1910</td>
<td>848</td>
</tr>
<tr>
<td>Iron Ore</td>
<td>0</td>
<td>2900</td>
<td>1000</td>
<td>2480</td>
</tr>
<tr>
<td>Concrete</td>
<td>1394</td>
<td>844</td>
<td>1034</td>
<td>616</td>
</tr>
<tr>
<td>Total</td>
<td>4250</td>
<td>4250</td>
<td>4250</td>
<td>4250</td>
</tr>
</tbody>
</table>

Calculation of affordable cost reduction
The last step is to calculate the cost reduction afforded by each composition for each model of excavator. The calculation of cost reduction is mostly carried in simple mathematics method. Parameters that should be encountered are listed as:

- a. Purchasing price of steel scrap (PP)
- b. Re-selling price of steel scrap (SS)
- c. Purchasing price of brown iron ore, steel sand, and FS-55 (PL)
- d. Original cost of counter weight (OC), where steel scrap is totally used
- e. Planned Cost (PC); it is calculated based on mixture composition shown in Table 2
- f. Weight of scrap that can be sold out (WSS). WSS is equal to difference between original weight of scrap (OWS) and planned weight of scrap (PWS).

The following mathematics equation is used to simulate the affordable cost reduction for each model of excavator:

\[ ACR = OC - PC + ((SS - PP) \times WSS) = OC - PC + ((SS-PP) \times (OWS - PWS)) \ldots (1) \]

Here ACR is affordable cost reduction or the total cost reduction which can be obtained if steel scrap is used to replace or reduce the number of scrap. OC is varied by PP, PC is varied by PI and SS, and the term (SS – PP) x WSS is equal to a profit subject to the total weight of scrap that can be resold.

Figure 3a. Steel Scrap  
Figure 3b. Import Steel Sand- Magnadense
4. RESULT AND DISCUSSION

The process of mixing is carried out by manual process and the result for ZX200-1 Std is summarized at Table 2. Following the second step described at part 3 and utilizing the data resulted in Table 1 and Table 2 and comparing with the price that originated by using steel scrap and concrete, the simulation for each model of excavator has been done. In this simulation, some portion of steel scrap is replaced by FS-55 having density of 3.76 gr/cm³, while purchasing price of steel scrap (PP) of 0.4 USD per kilogram (USD/Kg) and the re-selling price (SS) of 0.49 USD/Kg are used. The result for each model is shown by Table 3.

Table 3. Simulation of Cost Reduction Result (FS-55 is used to replace or reduce steel scrap)

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ZX200-3Std</td>
<td>959</td>
<td>552</td>
<td>407</td>
<td>2076</td>
<td>196</td>
<td>603</td>
<td>62.9%</td>
</tr>
<tr>
<td>ZX200-3LC</td>
<td>1,477</td>
<td>1,139</td>
<td>338</td>
<td>1717</td>
<td>162</td>
<td>500</td>
<td>33.9%</td>
</tr>
<tr>
<td>ZX200-1Std</td>
<td>1,052</td>
<td>716</td>
<td>336</td>
<td>1693</td>
<td>160</td>
<td>496</td>
<td>47.2%</td>
</tr>
<tr>
<td>ZX200-1LC</td>
<td>1,614</td>
<td>1,357</td>
<td>258</td>
<td>1298</td>
<td>123</td>
<td>380</td>
<td>23.6%</td>
</tr>
<tr>
<td>ZX330-3Std</td>
<td>1,735</td>
<td>1,246</td>
<td>490</td>
<td>2527</td>
<td>239</td>
<td>728</td>
<td>42.0%</td>
</tr>
<tr>
<td>ZX330-2M</td>
<td>2,045</td>
<td>1,595</td>
<td>451</td>
<td>2313</td>
<td>219</td>
<td>669</td>
<td>32.7%</td>
</tr>
<tr>
<td>ZX110-1</td>
<td>275</td>
<td>131</td>
<td>144</td>
<td>625</td>
<td>59</td>
<td>203</td>
<td>73.9%</td>
</tr>
</tbody>
</table>

Assuming the parameters PP, SS, and PI as a variable to equation (1), the utilization of this equation to ZX200-1Std model gives a simulation result for several types of density and iron ore as shown by Figure 4. Vertical axis indicates the affordable cost reduction (ACR) and horizontal axis indicates the re-selling price of steel scrap (SS). The simulation result expresses that the affordable cost reduction amount or ratio is much depending on the parameters PP, SS and PI. Purchasing price of iron ore (PI) and re-selling price of steel scrap (SS) contribute a higher cost reduction since SS is fluctuating from time to time and relatively influenced by the global price of oil. PP does not give significant effect because the scrap is purchased in a several months contract basis. The following result and discussion can be summarized from Figure 4.
Figure 4. Simulation Result of Affordable Cost Reduction

a) Simulation for Local iron ore of 3.5 gr/cm³ in density shows that cost reduction is resulted (ACR>0) when the SS reaching the amount 0.15 USD/Kg. It is caused by the lower PP, the higher portion of PP and the lower portion of used scrap. However, the slope of the ACR is small although SS reaching the 0.66 USD/Kg.

b) By using Local iron ore of 4.2 gr/cm³, a positive ACR (>0) is reached from SS of 0.15 USD/Kg and increasing step almost double of 3.5 gr/cm³ one. However, there is difficulty in constant supplying of this material.

c) The ACR for import Magna dense is still negative (<0) until the SS of 0.31 USD/Kg. It is understood that the ACR increasing step is the highest among the 4 types of materials, however, since it is imported material the constant availability and lead time becomes a constraint. Furthermore, since the shape of this import iron ore is merely close to grain size of 2.5 mm, production workers find difficulty to do manual mixing. Therefore, new investment for mechanical mixer is required. During experiment, it was found that the usage of steel sand magna dense, with its density of 4.2 gr/cm³, to replace some portion of steel scrap can reduce the cost up to 30% compared with 100% using steel scrap.

d) The ACR for FS-55 is still negative (<0) until the SS of 0.20 USD/Kg. Comparing with the actual market price of steel scrap which currently at the average level of 0.44 USD/Kg, the level of 0.2 USD/Kg and even of 0.31 USD/Kg as been simulated for import magna dense is not much affecting to ACR. However, simulation results for all 4 kinds of iron ore as shown in Figure 4 clearly indicate that the ACR from FS-55 becoming highest starting from SS level of 0.37 USD/Kg. Surely, this material is the most effective to give higher profit and considered as an optimum condition for cost reduction of counter weight. Since FS-55 is locally produced and marketed, it is decided to continuously using this material to replace the steel scrap where the amount is adjusted following the above simulation results.

5. MATHEMATICAL MODEL TO OBTAIN AMOUNT OF COST REDUCTION

Those above results were merely obtained from implementation at production floor included utilization of simple mathematical formula. Furthermore, in order to have a general method to calculate the amount of cost reduction, the following mathematical model based on linear programming method is proposed. The model is developed for model ZX200-1 Std and using FS-55 as a replacement material to reduce the number of steel scrap mixed inside the counter weight.

There are some parameters and/or constraint that should be encountered such:

a. The total weight of counter weight should be at least of 4,250 kg,

b. The volume of counter weight should be maximum at 1,104 liter and

c. Technical difficulties at production floor and avoiding additional investment to execute this cost reduction program, a minimum volume ratio of steel scrap of 10% is required. It means that at least 110.4 liter of steel scrap volume should be used.

Thus, the model is developed as follows:
Weight equation is expressed by,

\[ X_1 + X_2 + X_3 + 306 \geq 4250 \]

or

\[ X_1 + X_2 + X_3 \geq 3944 \]  \hspace{1cm} (2)

Where \( X_1, X_2, \) and \( X_3 \) are variables for steel scrap, FS-55, and concrete mixed inside the counter weight, while figure 306 is the weight of the box itself. Unit is kilogram (Kg).

Based on actual result, the volume equation is expressed by,

\[ 0.127 X_1 + 0.266 X_2 + 0.389 X_3 \leq 1104 \]  \hspace{1cm} (3)

Where the unit used for volume is liter per kilogram (liter/kg).

Take into account the minimum volume of steel scrap that is 10% (=0.1), the volume equation (3) becomes:

\[ 0.127 \frac{X_1}{0.127 X_1 + 0.266 X_2 + 0.389 X_3} \geq 0.1 \]

Or it is simplified to be:

\[ 11.43 X_1 - 5.32 X_2 + 3.89 X_3 \geq 0 \]  \hspace{1cm} (4)

Simulation with purchasing price of steel scrap and FS-55 of 0.400 USD per kg and of 0.134 USD per kg each, and the production cost of concrete of 0.023 USD per kg, the total cost of counter weight composition filled inside the box is expressed as:

\[ 0.400 X_1 + 0.134 X_2 + 0.023 X_3 \]  \hspace{1cm} (5)

When the steel scrap is totally replaced with FS-55, i.e. the original weight of 2,250 kg is sold out with selling price of 0.490 USD per kg, there will be net selling income which following the equation of:

\[ (2250 - X_1)(0.490 - 0.400) = 202.5 - 0.090 X_1 \]  \hspace{1cm} (6)

Thus, the remaining cost of counter weight composition that should be minimized and it is obtained by deducting equation (5) with equation (6) to get minimized cost as:

\[ 0.400 X_1 + 0.134 X_2 + 0.023 X_3 - (202.5 - 0.090 X_1) \]

Or

\[ 0.490 X_1 + 0.134 X_2 + 0.023 X_3 - 202.5 \]  \hspace{1cm} (7)

Therefore, the linear programming model to get the minimized cost of counter weight composition becomes:

\[ 0.490 X_1 + 0.134 X_2 + 0.023 X_3 \]  \hspace{1cm} (8)

With constraints of:

\[ X_1 + X_2 + X_3 \geq 3944, \text{ i.e. equation (2)} \]

\[ 0.127 X_1 + 0.266 X_2 + 0.389 X_3 \leq 1104, \text{ i.e. equation (3)} \]

\[ 11.43 X_1 - 5.32 X_2 + 3.89 X_3 \geq 0, \text{ i.e. equation (4), and} \]

\[ X_1, X_2, X_3 \geq 0 \]

Linear programming solution of equation (8) gives the optimum combination of weight for each part of counter weight composition as: 869.29 kg for steel scrap, 1,646 kg for FS-55, and 1,428.70 kg for concrete. With this weight composition, the total weight of counter weight included box is maintained at 4,250 kg as well as the volume of 1,104 liter. Finally, the amount of cost reduction can be obtained.

Comparing with the experimental result using FS-55 shown at Table 2, the weight of steel scrap is closely same with variance of 2.5% since this condition was clearly defined as one of parameter for modeling (10% volume ratio). However, the variance of weight resulted for concrete and FS-55 were higher more than 40%. In term of cost reduction, this simulation result will not give much effect since the unit price of concrete is relatively same as price of FS-55. Further investigation related to rigidity of mixing inside the counter weight produced by smaller amount of concrete need to be proceeded.
6. CONCLUSION

Looking at the simulation and experimental results implemented to ZX200-1 Std, it is concluded that FS-55 is a material that can replace some portion of steel scrap with an optimum affordable cost reduction. It is also obtained that the purchasing price of replacement material such as FS-55 and re-selling price of steel scrap contribute a dominant portion of cost reduction. The mathematical model to obtain the weight of each composition mixed inside the counter weight is performed although high variance, compared with actual result, on the weight of FS-55 and concrete were more than 40%. Further investigation and calculation to verify the mathematical model is strongly recommended to be pursued.

7. REFERENCES

(d) Togar Harapan Pangaribuan, Cost Reduction in Manufacturing of Counter Weight used for Construction Machinery, presented in 2nd International Seminar on Industrial Engineering, 25th of October 2008

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MagnaDense™ is a tradename for Magnetite (Fe₃O₄) and it's most important property for use in Counterweight is HIGH DENSITY