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REDESIGN OF LIQUID ALUMINUM POURING TOOL BASED ON PARTICIPATORY ERGONOMICS TO IMPROVE PRODUCTIVITY, WORKLOAD, AND MUSCULOSKELETAL DISORDERS

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ABSTRACT

This research was conducted at P.T. "ED" Aluminium, Yogyakarta, an industrial aluminum foundry that produces manually operated cooking appliances. The workers complain of muscle pain and fatigue, and of always having to pursue production targets in order to fulfill goods shipment deadlines. Also evident was the unergonomic work system, where the liquid aluminum was often spilled due to workers having to adopt an unnatural work posture when pouring the liquid aluminum into molds. Therefore, the researchers' aims were to improve the operator's working posture, reduce the workload, eradicate musculoskeletal complaints, improve time efficiency, and increase productivity by redesigning the liquid aluminum pouring tools using an integrated participatory ergonomics method combined with an appropriate technology (AT) concept. Furthermore, ergonomics intervention was conducted in the redesigning of the pouring tools. The result was an ergonomic liquid aluminum pouring tool. The ergonomics intervention results from use of the newly designed pouring tools allowed for a more natural working posture, improvement in the workload category from heavy to medium, a 26.13% reduction of the workload, and a 19.64% reduction in musculoskeletal disorders. Time efficiency increased by 25.81%, and productivity increased by 26.60%.

Keywords: Liquid aluminum pouring tool; Musculoskeletal disorder; Participatory ergonomics; Workload

1. INTRODUCTION

This research was carried out at P.T. "ED" Aluminium, Yogyakarta, an industrial aluminum foundry that produces manually operated cooking appliances, a process that requires movement of the operators' hands by moving, lifting, lowering, filling, emptying, or carrying a container manually (Cheung et al., 2007). Manual work carries the potential for industrial accidents and occupational diseases (Manuaba, 2003).

The predominant work characteristics of the casting production process in the molding division of P.T. "ED" Aluminium require a relatively large exertion of muscular force for lifting, carrying, and pouring the liquid aluminum into the mold. In conducting their work, the workers need high levels of precision and patience. Much of the work was done in the standing, walking, or bending positions, and workers had to adjust their body posture to suit the

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equipment used. The repetition rate of work for one type of muscle was very high. Such working conditions forced the workers to remain in a bad posture and an unnatural working position throughout their time at work.

In preliminary studies, it was observed that the liquid aluminum pouring tool was too shallow. This led to excessive cooling, which resulted in casting defects and spillages during the process of transporting the molten metal from the melting furnace to the molds. Spillage of liquid aluminum at that temperature (675^{o}C) is extremely dangerous to the workers who, if they came into contact with it, would suffer severe pain from burns and blistered skin. In addition to losses due to the workers' incapacitation, the company would suffer losses due to the waste of the spilled raw materials. There were other working conditions that also had negative impacts on the workers. The size of the tool handle was too large and uncomfortable to hold. The handle angle in relation to the ladle was at 50^{o}C, which necessitated maintaining an unnatural body posture while pouring the liquid aluminum into the mold, with the right elbow bent, shoulders lifted upward, and the left arm above shoulder height (sometimes even above head height).

In addition to unnatural working postures, the workers were also exposed to heat emanating from the work object itself, (i.e, the liquid aluminum with a temperature ranging between 650–675^{o}C). To achieve production targets in accordance with high quality and quantity standards, the workers are required to have high productivity and be able to fulfil the buyers' demands, such as goods delivery deadlines and the quality and quantity of products. Such conditions lead to workers being constantly under pressure to achieve production targets. To identify potentially unsafe and unhealthy effects on workers, an evaluation was carried out based on several aspects of ergonomics problems, such as working nutrition, exertion of muscle force, workload, musculoskeletal complaints, and working time efficiency.

From the point of view of problems caused by workstation ergonomics, these were rectified using a participatory ergonomics approach to redesign the liquid aluminum pouring tools. The purpose of the redesign was to help correct working posture, reduce the workload, decrease musculoskeletal complaints, improve the time efficiency of the production processes, and to improve overall productivity.

Two studies related to ergonomics were previously conducted in this company, one by Oesman (2014) who conducted a study on the evaluation of working conditions in the casting process of the aluminum cast craft industry of P.T. "ED" Aluminium, Yogyakarta, and Batubara (2010) who conducted a study on work system evaluation based on ergonomics in P.T. "ED" Aluminium, Yogyakarta. Neither researcher performed ergonomics intervention, but rather limited their research to ergonomics evaluation. Therefore, in this study, system repair work was carried out using participatory ergonomics and intervention.

An ergonomics intervention should be conducted using a participatory approach (St. Vincent et al., 2001; Wells et al., 2003). A participatory approach is the most effective method to reduce the number of musculoskeletal complaints suffered by workers (Hess et al., 2004). Intervention using a participatory ergonomics approach is more effective than the conventional method in reducing musculoskeletal complaints, levels of employee absenteeism, and in making psychosocial improvements in the working environment (Rupesh, 2006).

Intervention was conducted using a participatory ergonomics approach integrally merged with the appropriate technology (AT) concept. The purpose of a participatory approach is to provide opportunities for workers to design and control the working system with ergonomics intervention from ergonomics experts (de Jong & Vink, 2002).

Through the application of participatory ergonomics, the improvement of working conditions was expected to create a healthy work environment that is safe, comfortable, efficient, and productive, and which will reduce workload and musculoskeletal complaints, as well as improve time efficiency and productivity.

2. EXPERIMENTAL METHOD

Data collection of human to machine/tool interaction and working posture was done using a digital camera. The workload category was measured using a stop watch to check the subjects' heart rates. Musculoskeletal complaints were gauged using a Nordic Body Map (NBM) questionnaire. The questionnaire was completed before and after working, both pre- and post-ergonomics intervention. The musculoskeletal complaints perceived by subjects in different parts of the body were measured as follows: (1) no pain; (2) a little pain; (3) pain; or (4) very painful.

The redesign of the tools was done using the workers' anthropometry, especially in areas of the body related to tool use. The operator anthropometry measured for the tool design included the grip height (knuckle height) with the arm in a relaxed downward position to determine handle length, and the shoulder and elbow heights to determine the tool angle during pouring and the optimal grip diameter.

Rectification of these problems was performed using a participatory ergonomics approach with the AT concept. Participatory ergonomics begins with the planning, designing, and controlling process of a number of activities and involves the input of knowledge from the user, a technician, or a maker in a process to achieve a goal (Hignett et al., 2005). The problems found in the ergonomics evaluation were discussed by forming a team consisting of a variety of disciplines referred to as the Focus Group Discussion (FGD) team. The measurement results leading towards ergonomics evaluation were first socialized through meetings of the FGD team and involved all parties taking part in the work system. The FGD team consisted of two ergonomists, one engineer (the head of Human Resources Development), two quality experts (the head of production and the head of warehouse materials), an economist (the head of the company), and two employee representatives to actively participate in solving the problems.

The FGD applications in this study relate to the total ergonomics as follows:

- The measurement results of preliminary studies to be socialized through meetings with the FGD team to obtain an immediate response and strengthen the results of data analysis so that existing problems could be thoroughly explored.
- Determination of the priority of problems to be solved collaboratively, that is, between the researchers and the company so that the solutions obtained were based on holistic thinking.
- Determination of the best possible improvements by intensively engaging employees and experts who were involved to help improve working conditions in the molding division.
- The FGD results indicated that priorities for improvement were redesigning the pouring tools (hot aluminum lifters), adjusting them to operator anthropometrics.

After the redesigned pouring tools had been completed, the ergonomics intervention was made to find out whether the rectification of the work system after intervention could reduce the workload, reduce musculoskeletal complaints, improve time efficiency, and increase productivity. Ergonomic evaluation was performed for six days.

Data processing for measuring the results was performed using the SPSS for Windows program. The normality test of pulse data, musculoskeletal complaints data, exhaustion data, data for processing time of production, physical environment data, and working productivity data for all conditions was done with the Kolmogorov-Smirnov (KS) test. The difference test to find out the difference between conditions before intervention and conditions after intervention was undertaken using the paired sample t-test when data was normally distributed at a significance level of 5%. If data was not normally distributed, then the nonparametric Wilcoxon tests were used.

3. RESULTS

3.1. Working Nutrition

Working nutrition was measured through characteristics indicators of 14 male workers, including age (in years), body height, and body weight. The average age of research subjects was 32.64±9.83, with a range of 18–53 years, showing there were unproductive age ranges. The productive age ranged from 15–40 years (Grandjean & Kroemer, 2000). The average body height of a research subject was 160.71±7.66 cm, and the average weight was 54.89±9.22 kg.

The body height and weight are most influential in the Body Mass Index (BMI). BMI is a standard that is commonly used to determine ideal weight and thus assess personal nutrition. A BMI less than 18.5 is considered underweight, a BMI from 18.5–24.9 is considered normal, a BMI from 25.0–29.9 is considered overweight, and a BMI greater than 30.0 is considered obese (National Obesity Observation, 2009). The research subjects had an average BMI of 21.23±3.01, therefore, it could be concluded that respondents had normal BMI levels and were assumed to have a good nutritional intake.

3.2. Redesign of the Liquid Aluminum Pouring Tool

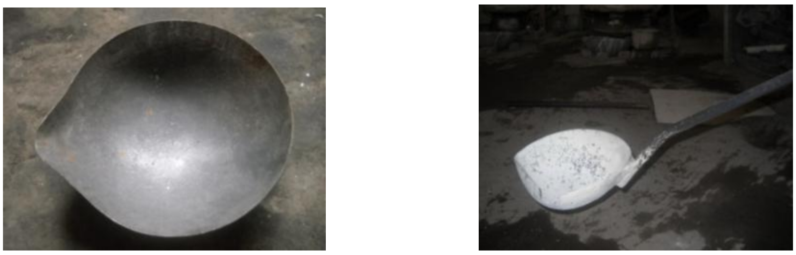
The old pouring tool used in the working procedures for pouring aluminum into the mold was made from used bitumen drums formed into a hemispherical shape and with a handle made of iron. These tools play a large part in workers having to conduct their duties with an incorrect physiological posture. The old pouring tool consists of two parts, the ladle and the handle. The tool is made of iron with a 29 cm diameter, a 5.7 cm depth, and is equipped with a short 23.5 cm handle. An indentation is made in the middle. The pouring tool is then shaped into a spout to facilitate the pouring of the liquid aluminum into a mold. The tool handle is then spliced with an iron handle 245 cm in length and 3.6 cm in diameter. The total weight of this pouring tool is 3 kg as presented in Figure 1.

(a) Tool before formed (b) Tool after shaping (c) Tool connected to iron handle

Figure 1 Old pouring tools

The grip height (knuckle) in the downward relaxed position was measured to design the tool handle length. Shoulder and elbow heights were measured to determine the tool angle in the pouring position, and maximum grip diameter was measured to determine the optimal tool handle size. The mold height measured between 54–74 cm. The pouring tool handle length remained unchanged at 245 cm for compliance with the workers' anthropometry. The sizes of the aluminum pouring tools can be seen in Table 1.

For the higher aluminum molds (74 cm), the workers pour aluminum using a footstep, so that when pouring the liquid aluminum into the mold, the arm positions remain natural. The size of the step is not intrusive, and it is flexible and easily applied to any mold. The user can step up and down while carrying the liquid aluminum material safely and comfortably.



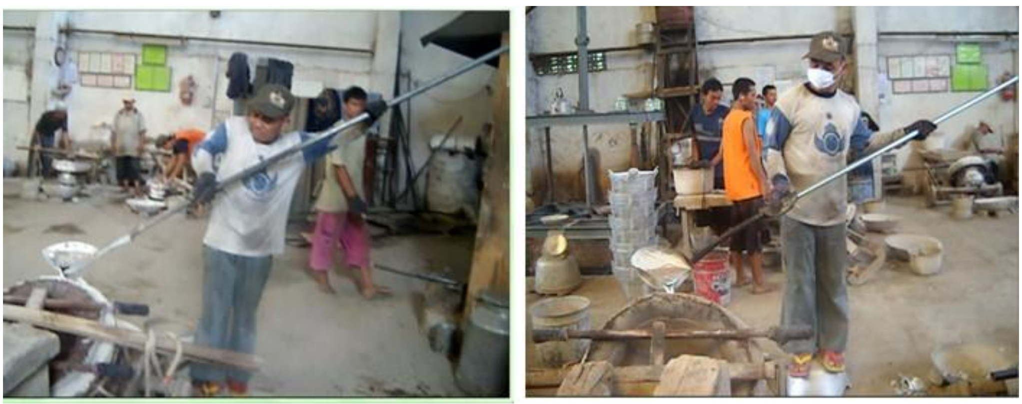
(a) Pouring tool (ladle) without handle (b) Pouring tool connected to iron handle

Figure 2 Redesigned pouring tool

Table 1 Sizes of liquid aluminum pouring tools

Specifications of Pouring Tool	Old Pouring Tool	New Pouring Tools
Pouring Tool (ladle) diameter (cm)	29.0	26.0
Tool depth (cm)	5.7	8.5
Short handle (cm)	23.5	-
Iron handle length (cm)	245	245.0
Handle diameter (cm)	3.6	2.8
Tool weight (kg)	3.0	2.0
Capacity (kg)	3.2	4.0

The footsteps used were adjusted in accordance with the comfort of stepping upwards. For example, when climbing stairs, the ideal standard step size is between 15–20 cm (Permana, 2008). The footstep used was made by utilizing material from failed products. The step height was 16 cm and the diameter was 28 cm. The use of footsteps and redesigned pouring tools effected the necessary changes to the unnatural working posture caused by using the old pouring tools (Figure 3a) to become more natural (Figure 3b) due to the height range of the worker's left hand being lower than the height of his shoulders.



(a) Using old tools (b) Using new tools

Figure 3 Working posture

3.3. Workload

Workload was measured using the heart rate of the employees. Workload ratings can be made indirectly by recording pulse measurements during work (Wickens et al., 1998). The severity of workload is based on metabolism, respiration, body temperature, and heart rate. The workload rating is made by measuring the increase in heart rate held at work and when work is finished. This process rates cardiovascular strain using the 10 heart rate method (Louhevaara & Kilbom, 2005). The measurement results showed the heart rate of employees before the intervention of the new liquid aluminum pouring tool in the molding section to be 100 to 140.15 beats/min. If the minimum heart rate is between 125 to 150 beats/min, the workload is categorized as a "heavy workload."

Table 2 Difference test of employees' heart rate before and after intervention

No	Variable	Before Intervention Mean ± SD	After Intervention Mean ± SD	*Z*	*p*
1	Resting heart Rate	68.79 ± 4.21	68.28 ± 1.85	0.85	0.400
2	Working heart Rate	140.43 ± 11.20	101.43 ± 2.85	3.30	0.001
3	% CVL	38.00 ± 10.56	28.07 ± 3.27	3.19	0.001

To find the difference in pulse rate before and after intervention, statistical analysis was performed as shown in Table 2. The results of a normality test for the Resting Pulse Rate (RPR), Working Pulse Rate (WPR), and Workload (W) before intervention and after intervention showed that not all data were normally distributed ($p<0.05$). Therefore, nonparametric paired sample t-tests were used.

Table 3 The percentage of decrease in working pulse and CVL

Variable	Before Intervention Mean ± SD	After Intervention Mean ± SD	Average Decrease (%)
Working heart rate	140.43 ± 11.20	101.43 ± 2.85	27.78
CVL	38.00 ± 10.56	28.07 ± 3.27	26.13

To determine the percentage of decreased levels in pulse rate and cardiovascular load (CVL), descriptive analyses were conducted, and the results are presented in Table 3. These results show an average decline of workload 38.00 ± 10.56 before intervention to 28.07 ± 3.27 after intervention. If CVL<30%, it is classified as not incurring fatigue (Tarwaka & Sudiajeng, 2004).

3.4. Musculoskeletal Complaints

Musculoskeletal complaints are a group of conditions affecting the muscles, tendons, ligaments, joints, peripheral nerves, and supporting blood vessels in the body (Punnett & Wegman, 2004). These complaints are usually termed musculoskeletal disorders (MSDs) and represent complaints or injury to the musculoskeletal system (Grandjean & Kroemer, 2000).

The NBM questionnaires were modified with a 4-point Likert scale. These are valid and reliable and are used internationally to record musculoskeletal complaints. The NBM questionnaire is a subjective assessment using a body map to help understand complaints regarding muscles with complaint levels ranging from mild discomfort to pain. Musculoskeletal complaints were measured before working and when the work had just finished, with both the old and the new pouring tools.

The normality test results showed that not all score data of MSD before and after working have normal distributions ($p>0.05$). The results of the statistical description of the mean scores of NBM before working, both pre- and post-intervention, to be 34.43±2.85 and 34.00±2.11, respectively. The average score for the difference test of musculo-skeletal complaints before working, both pre and post intervention, obtained a value $Z = 1.05$ and $p =$ 0, 294 ($p>0.05$). Based on these results, the initial condition of employee complaints, both pre and post intervention, was not significant, in other words, there was no cumulative effect of muscle complaints from previous working conditions.

The average musculo-skeletal complaint after working, pre and post intervention was 44.43±10.55 and 37.79±4.69, respectively, value $Z = 3.18$ and $p =$ 0.0 01 ($p<0.05$) means there was a significant difference in skeletal and muscular complaints both before and after intervention, can be seen in Table 4.

Table 4 Difference test of NBM scores of employees

No.	Variable	Before Intervention Mean ± SD	After Intervention Mean ± SD	Z	p
1	NBM Score (Before Working)	34.43±2.85	34.00±2.11	1.05	0.294
2	NBM Score (After Working)	44.43±10.55	37.79±4.69	3.18	0.001

The percentage decrease in the level of musculoskeletal complaints, as presented in Table 5, shows that the number of employees who did not have complaints (“no pain”) increased by 27.7%. The number of employees who complained of “a little pain” decreased by 1.45%, and in those complaining of “pain,” the level decreased from 13.3% to 0% (pain was no longer felt). It is clear that ergonomics intervention using the participatory method can significantly reduce the level of musculoskeletal complaints.

Table 5 The decrease of percentage in musculoskeletal complaints

Skeletal Musculoskeletal Complaint		Number of Employee Complaints			
No	Complaint Level	Before Intervention (%)	After Intervention (%)	Decrease (%)	Enhancement (%)
1	No pain	51.41	65.65	-	19.64
2	A little pain	35.29	34.35	1.45	-
3	Pain	13.03	0	13.03	-
4	Severe pain	0	0	-	-

3.5. Productivity

The molding division’s end-product is cooking equipment, such as pans, boilers, cake molds, etc. This research examined the pan-type cooking equipment. The time duration of the production process is the process of pouring molten aluminum into a mold. Normality tests for processing time during the pouring of molten aluminum into a mold indicated that the data are not normally distributed ($p<0.05$). Therefore, the results of the test for the time differences in the process, performed by a nonparametric Wilcoxon test, are presented in Table 6.

Table 6 shows that the average frequency of the aluminum pourings before intervention was 49.43 ± 9.19 times and after intervention was 36.57 ± 8.10 times with a value of $Z = 2.371$ and $p = 0.018$ ($p < 0.05$). It can be concluded that the frequency of the process of pouring molten aluminum was significant (made a significant difference). Thus, use of ergonomics interventions improved the efficiency of the casting process time per day by 25.81%.

Table 6 Test of the time differences in the production process of cooking utensils

	Before Intervention Mean ± SD	After Intervention Mean ± SD	*Z*	Sig. (2-tailed)
Frequency	49.43 ± 9.19	36.57 ± 8.10	2.371	0.018

Table 7 Difference test of total production of cooking equipment in aluminum molding division (pcs/day)

Variable	Before Intervention Mean ± SD	After Intervention Mean ± SD	*t*	*p*
Total Production	870.17 ± 102.63	1185.67 ± 83.17	-9.46	0.000

The normality tests for production numbers for all kinds of products, either pre- intervention or post-intervention, have a normal distribution ($p>0.05$). Therefore, a difference test of total production, pre-intervention and post-intervention, was used. The paired sample t-test results are presented in Table 7. The average production per day numbers increased by 26.60%.

4. DISCUSSION

In the old pouring tools, the form was rather flat, which not only encouraged spillage of the molten aluminum, but also contributed to the rapid temperature drop of the molten aluminum, which could result pouring tool (ladle) in 26 cm and a depth of 8.5 cm without a short handle. In the old pour tools, the tools form is rather flat so that when carrying aluminum often spilled out and can cause temperature of the liquid aluminum down quickly resulted in the printout defects. The capacity of the old pouring tool was 3.2 kg. The redesigned tool has a length of 245 cm and a diameter of 2.8 cm. The newly designed pouring tool is more concave to lessen the possibility of spillage and to help maintain the temperature of the liquid aluminum at between 600–675^{o}C. The total weight of the modified pouring tool is 2 kg.

The statistical description in Table 2 shows that the average RPR before intervention was 68.79±4.21 and 68.28±1.85 after intervention with a value of $Z = 0.85$ ($p>0.05$). This means that the RPR was no different before the intervention than after the intervention. It could therefore be concluded that the employee’s RPR condition before working activity begins was equal. In addition, the WPR was 140.43±11.20 before intervention and 101.43±2.85 after intervention. The heart rate of between 100–125 beats/min was categorized as a medium workload (Christensen et al., 1999). Difference tests showed values of $Z = 3.30$ and $p = 0.001$ ($p<0.05$), which means that the WPR before intervention and after intervention were significantly different. The CVL percentage before intervention was 38.00 ± 10.56 and 28.07 ± 3.27 after intervention with values of $Z = 3.19$ and $p = 0.001$. This means that ergonomics intervention reduced the employees’ pulse rate, which indicates a decrease in their workload.

The averages of musculoskeletal complaints after work, before and after intervention respectively, were 44.43±10.55 and 37.79±4.69, with a value of $Z = 3.18$ and $p = 0.001$ ($p<0.05$), which shows there to be a significant difference in musculoskeletal complaints before and after intervention.

5. CONCLUSION

Employees at P.T. "ED" Aluminium, Yogyakarta complained of being very tired and always having to rush their work to meet deadlines. In addition, the liquid aluminum pouring tool used to transport molten metal from the furnace to the mold lacked stability, which often led to

spillages. The poorly designed tool required a high degree of caution in its use, and the oversized handle made it uncomfortable to carry.

These problems were submitted to the head of the company. Discussions with the FGD team were also conducted to explore more specifically the problems that existed in the workplace and to understand employees' desires for changes in the work systems. The head of the company then determined the main priorities for improvements to be executed. The improvement carried out was to redesign the liquid aluminum pouring tools. The FGD team also emphasized to employees the importance of drinking regularly to avoid dehydration and the need to consistently use personal protective equipment, such as masks, gloves, and earmuffs.

The liquid aluminium pouring tools were redesigned based on the workers' anthropometrics, and then interventions were made. This redesigned pouring tool can correct an unnatural working posture and reduce the amount of liquid aluminum lost to spillages. The intervention results showed that by using the new liquid aluminum pouring tools, the workload decreased by 26.13%. The workload category was downgraded from heavy to moderate. The musculoskeletal complaints decreased by 19.64%. Time efficiency increased by 25.81%. Productivity of manufacturing pan-type products increased by 26.60%. This new liquid aluminum pouring tool (ladle) can also be used in other companies engaged in aluminum casting.

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