International Journal of Applied Sciences: Current and Future Research Trends

( IJASCFRT )

ISSN (Print) , ISSN (Online)



https://ijascfrtjournal.isrra.org/index.php/Applied_Sciences_Journal

# The Use of Low-Cost Forging Hammers to Increase Blacksmith Productivity in Various Working Environments

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**Abstract**

Blacksmithing is one of the micro-enterprises in Bali, Indonesia, where traditional tools such as hand hammers are still used to make iron-based home appliances and souvenirs. The process is typically divided into two general steps, which begin with smelting/heating the metal materials and continue with repeatedly forging the materials by using a hand hammer. This traditional forging method has proven to be inefficient, taking a relatively long time and increasing the blacksmith's fatigue and musculoskeletal complaints, resulting in highly inefficient production. Therefore, in order to improve the efficiency in the forging process, this study develops a low-cost forging machine that could reduce the fatigue and musculoskeletal complaints of the blacksmith while also increasing the production number. The sample of this study takes place in Gubug village, Tabanan district, Bali Indonesia which includes 30 blacksmiths with normal anthropometric measurement. For the experimental method, a one-shot case study was implemented with a pre and post-test design group. In addition, this study also used two set environmental conditions which are based on different control temperatures. The results demonstrate that 30 blacksmiths showed a decrease in workload based on the work pulse, from 120.76 ± 3.02 bpm (when using hand hammer) to 88.50 ± 2.43 bpm (after using the proposed machine) ($p<0.05$). In addition, this study also observed a decrease in subjective complaints based on fatigue scores from 43.10 ± 2.08 to 33.90 ± 3.21 ($p <0.05$). In terms of musculoskeletal complaints, when the blacksmith used conventional tools, the complaints were 42.74 ± 3.48, however, when the proposed machine was used, their complaints were reduced to 31.83 ± 3.06 ($p <0.05$). The result from this study shows that environmental conditions such as setting a lower temperature in the forging area also could reduce the blacksmith’s workload, fatigue, and musculoskeletal complaints even better by a significant margin ($p<0.05$) based on paired T-test. When measuring productivity with a traditional tool, the result is 0.0263 ± 0.0028; however, when using the proposed machine, the result increased to 0.0326 ± 0.0081 ($p <0.05$), in other words, utilizing the proposed forging machine could increase 23.9% of blacksmith productivity.

***Keywords:*** Ergonomics; Forging hammer; Musculoskeletal complaints; Work productivity.

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## 1. Introduction

Micro-enterprises are one of the major occupations in Bali, Indonesia which includes arts and crafts. Since Bali is well-known for its tourist attractions, the sale of handcrafted products such as jewelry, clothing (such as songket, endek, and so on), statues, metal crafts, and so on is the primary source of income for residents. Among all the crafted products in Bali, metal crafts and jewellery are the most popular handicraft among both local and international tourists. However, because craftsmen, particularly blacksmiths, in Bali are still micro-enterprises, the equipment that used in the production process is still traditional. As a result, the blacksmith in Bali is having difficulty meeting market demand while also taking a reasonable amount of time. In general, the process of blacksmithing is divided into two processes which are started from the smelting/heating process and then continue to forging/hammering to transform the metal into the desired shape. Currently, the forging/hammering process is still done by hand, but it is considered inefficient because it consumes a lot of energy and takes a long time. In addition, conventional hammering for a long time also raises the fatigue and musculoskeletal complaints of the blacksmith. Working while having musculoskeletal complaints have a significant impact on the workforce in terms of presenteeism (lowered performance and productivity), absence due to injury/sick, and long-term incapacity for work [1]. To address these issues, this study develops a working mechanism using a low-cost forging hammer machine to optimize the forging/hammering process while reducing fatigue, workload, and musculoskeletal complaints. The pressure of the proposed forging hammer machine can be adjusted to mimic human hammering behavior. Furthermore, it could also be operated continuously at the same/constant pressure, resulting in a more uniform and precise product. The engine is propelled by the rotation of the electric motor, which is transmitted to the V-belt, which moves the hammer vertically. The component of the machine will be produced at a low cost while maintaining safety, allowing micro-enterprise subjects to afford the machine. Thus, this study expects that the low-cost forging hammer machine will aid blacksmiths in the forging process by producing better and more consistent results compared to the using conventional method.

## 2. Methodology

This experiment follows a one-shot case with a pre-test and post-test design group that was undertaken observationally during the use of conventional tools and continue to use of low-cost forging hammer machine. The diagram is given as follows:

$$R \longrightarrow P0 \longrightarrow PI$$

**Figure 1:** Experiment design.

Where:

R = Random samples.

P0 = the result of the pre-test observation.

PI = the result of the post-test observation.

The scope of this study includes developing an ergonomic forging tool as well as analyzing their workload, productivity, and musculoskeletal complaints after using the proposed machine. The forging hammer machine model is ergonomically designed to use an electric motor to drive the V-belt and swing arm. In addition, this study also set two different environmental conditions with different room temperatures. The first condition is treated as the control group, with less ventilation and a temperature of 36–37oC. The second condition is treated as the treatment group, in which the room has adequate ventilation and a cooler that can keep the temperature around 27oC. Later, their workload, fatigue, and musculoskeletal complaints are measured to determine the influence of the environmental condition on the blacksmith's health and physique. This study invites 30 blacksmiths from Gubug village, Tabanan district, which is one of the main forging centers in Bali. Following that, each subject had Anthropometric measurements taken. According to the measurements, the average age of the subjects in this study was 37.15 ± 4.50 years, their average height was 168.55 ± 4.01 cm, their average body weight was 64.14 ± 2.12 kg, and their average work experience was 10.03 ± 2.78 years. Based on their age, weight, and height, the subject was classified as normal. The hand anthropometric measurement for the fifth percentiles is palm length 17.83 cm, palm width 9.88 cm, and elbow height standing 105.37 cm. The length of the palm for the 50th percentile is 18.88 cm, the width of the palm is 10.32 cm, and the height of the standing elbow is 106.55 cm, while the length of the palm for the 95th percentile is 19.45 cm, the width of the palm is 11.02 cm, and the height of the standing elbow is 107.9 cm.

## 3. Results and Discussions

### *3.1. Ergonomics Principle of Low-cost forging hammer machine*

The application of ergonomics principles is a form of intervention that aims to obtain a humane, competitive, and sustainable work system [2]. Ergonomics applications in general have several goals to be achieved. The main goal is to create a healthy physical and psychological state of workers, by harmonizing human abilities and limitations with the task or work to be carried out. Ergonomics application in addition to creating a humane work system has also been proven to provide economic benefits. Good ergonomics is good economics [3] which means that the correct application of ergonomics will provide higher economic benefits, and it has been proven by the application of ergonomics in different study fields such as forestry industry, transportation, material handling systems, product design, repair of workstations, and other areas where productivity can be improved. Ergonomics, in particular, will provide several benefits, including [4]; [5]: (a) more efficient use of muscle and energy; (b) reduced fatigue; (c) more efficient use of time; (d) reduced work accidents; (e) increased job comfort and satisfaction; (f) reduced work-related illnesses; (g) increased work efficiency; (h) reduced work errors and difficulties; (h) increased product quality and work productivity; and (j) reduced expenses or costs to overcome the consequences of accidents and occupational diseases. As a result, a forging hammer can be customized to meet the needs of the blacksmith. A forging machine that is powered by an electric motor to rotate the V-belt and swing arm, simulating the human hammering movement of swinging the hand hammer up and down. This machine is very simple to use and speeds up the forging process, both for initial and finishing work, because it can provide the same and evenly pressure in every beating. Figure 2 depicts the design of the low-cost forging hammer machine.

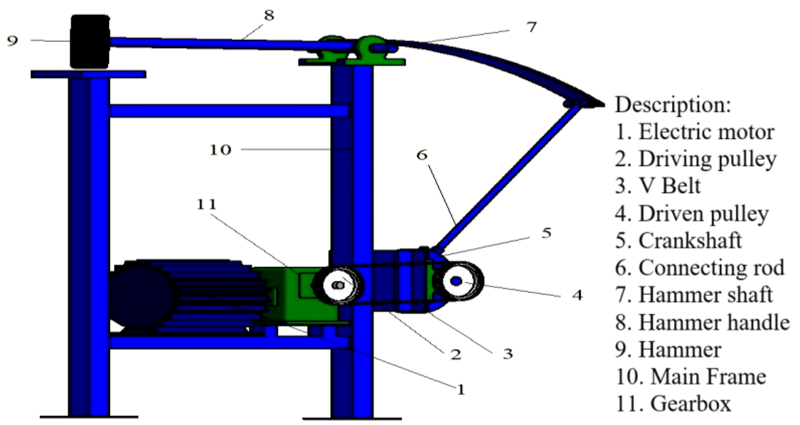


**Figure 2:** Design of low-cost forging hammer machine.

The proposed machine is designed to be simple and safe to use. Furthermore, the equipment used in this machine is kept at a low cost, particularly in simplifying the mainframe, so it can be afforded by the blacksmith. This tool has never been seen among blacksmiths, particularly in the Tabanan area of Bali. This forging hammer machine is expected to shorten the forging time and produce more even and uniform results. As a result, the manufacturing process could be accelerated, and the productivity of blacksmiths is increased.

### *3.2. Workload*

The workload of the blacksmith is indicated by their pulse. Before the experiment was conducted, this study measured the blacksmith's initial pulse (pre-test). In addition, the Shapiro-Wilk normality test is used to illustrate that data are normally distributed. According to the normality test, the p-value in both pre and post-test are above 0.05 which means the data are normally distributed. Because the data are normally distributed, the mean difference test can be replaced with the Independent-Samples T-Test. Table 1 (heart rate before work) shows the initial pulse rate of blacksmith craftsmen from 30 subjects. The results show that there is no statistically significant difference ($p > 0.05$) in the initial pulse in either design group. In other words, that the average resting pulse rate before and after using the forging machine can be considered the same or the two groups are comparable in both environmental conditions.

**Table 1:** The difference in the average of initial/resting pulse before using both conventional and low-cost forging hammer machine (pre-test) (n=30).

| **Group** | **Average of Resting Pulse Per-minute (bpm)** | **SD** | ***t*** | **p** |
|---|---|---|---|---|
| Room Temperature 36-37$^{o}$C (Control Group) | | | | |
| Pre-test Conventional Tools | 75.18 | 2.19 | 0.69 | 0.529 |
| Pre-test low-cost forging hammer machine | 76.19 | 2.81 | | |
| Room Temperature 27$^{o}$C (Treatment Group) | | | | |
| Pre-test Conventional Tools | 68.28 | 2.24 | 0.62 | 0.660 |
| Pre-test low-cost forging hammer machine | 67.43 | 2.77 | | |

SD = standard deviation

The average working pulse rate was also measured after using the forging hammer machine. The measurements result is illustrated in table 2. The result shows that there is a significant difference when the blacksmith used a hand hammer and the proposed machine ($p < 0.05$). In terms of environmental conditions, the test is divided into a control group which is using the real temperature in the forging area (36-37oC), and a treatment group where the room temperature is maintained around 27oC. Thus, this study used paired t-test to show the difference between the two groups. The result illustrates that keeping the working environment at a cooler room temperature (27oC) show a significant decreasing ($t = 3.21$, $p<0.05$) in the workload (average pulse per-minute) from 88.50 ± 2.43 bpm to 74.65 ± 3.16 bpm, where this result is consistent with [6].

**Table 2:** The difference in the average of initial/resting pulse after using both conventional and low-cost forging hammer machines (post-test) (n=30).

| **Group** | **Average of Resting Pulse Per-minute (bpm)** | **SD** | ***t*** | **p** |
|---|---|---|---|---|
| Room Temperature 36-37$^{o}$C (Control Group) | | | | |
| Pre-test Conventional Tools | 120.76 | 3.02 | 15.33 | 0.001 |
| Pre-test low-cost forging hammer machine | 88.50 | 2.43 | | |
| Room Temperature 27$^{o}$C (Treatment Group) | | | | |
| Pre-test Conventional Tools | 113.29 | 3.96 | 12.48 | 0.001 |
| Pre-test low-cost forging hammer machine | 74.65 | 3.16 | | |

SD = standard deviation

### *3.3. Musculoskeletal Complaints*

Tables 3 and 4 show that the p-value of musculoskeletal complaints before and after work on blacksmith who still uses hand hammer and blacksmith who use a forging hammer machine is above 0.05, implying that the data on musculoskeletal complaints before and after work is normally distributed. The average musculoskeletal complaints before and after using a forging hammer machine were used to compare the effects of using a forging hammer machine. According to the result in table 3, the musculoskeletal complaints of the blacksmith were similar before conducting the experiment (P*****>0.05) which means they are robustly comparable.

**Table 3:** Data on musculoskeletal complaints before using both conventional and low-cost forging hammer machines (pre-test) (n=30).

| **Descriptions** | **Conventional tools** | | | **Low-cost forging hammer machine** | | | **P*** |
|---|---|---|---|---|---|---|---|
| | **Mean** | **SD** | **p** | **Mean** | **SD** | **p** | |
| Pre-test room temp 36-37$^{o}$C (musculoskeletal complaints) | 28.88 | 1.60 | 0.212 | 39.14 | 2.18 | 0.319 | 0.260 |
| Pre-test room temp 27$^{o}$C (musculoskeletal complaints) | 22.12 | 1.23 | 0.491 | 22.24 | 1.88 | 0.427 | 0.179 |

p = Significance for normality, P* = Significance for comparability

Table 4 shows the findings of the analysis. The significance analysis with the Independent-Samples T-Test showed that the value of P*=0.001. This means that the mean score of musculoskeletal complaints after using a forging hammer machine is significantly different (P*<0.05) or indicates that there is an effect of using a forging hammer machine on reducing musculoskeletal complaints. In addition, lower room temperature during the forging process could reduce blacksmith's musculoskeletal complaints by a significant margin (t = 4.57, p<0.05).

**Table 4:** Data on musculoskeletal complaints before using both conventional and low-cost forging hammer machines (post-test) (n=30).

| Descriptions | Conventional tools | | | Low-cost forging hammer machine | | | P* |
|---|---|---|---|---|---|---|---|
| | Mean | SD | p | Mean | SD | p | |
| Pre-test room temp 36-37$^o$C (musculoskeletal complaints) | 42.74 | 3.48 | 0.134 | 31.83 | 3.06 | 0.102 | 0.001 |
| Pre-test room temp 27$^o$C (musculoskeletal complaints) | 35.51 | 3.23 | 0.260 | 25.94 | 3.17 | 0.144 | 0.001 |

*p = Significance for normality, P* = Significance for comparability*

### *3.4. Fatigue*

Tables 5 and 6 shows that the p-value of fatigue both in pre and post-test on the blacksmith when using the hand hammer and low-cost forging hammer machine is greater than 0.05 in both environmental conditions, implying that the data is normally distributed. The treatment effect analysis was performed using the average fatigue score between the blacksmith groups when using different tools. Table 6 shows the findings of the analysis.

**Table 5:** Data on fatigue before using both conventional and low-cost forging hammer machines (pre-test) (n=30).

| Descriptions | Conventional tools | | | Low-cost forging hammer machine | | | P* |
|---|---|---|---|---|---|---|---|
| | Mean | SD | p | Mean | SD | p | |
| Pre-test room temp 36-37$^o$C (fatigue) | 32.79 | 1.36 | 0.102 | 32.60 | 1.55 | 0.202 | 0.501 |
| Pre-test room temp 27$^o$C (fatigue) | 28.69 | 1.28 | 0.225 | 28.71 | 1.91 | 0.412 | 0.492 |

p = Significance for normality, P* = Significance for comparability

According to Table 6, the average fatigue score for a blacksmith who worked using conventional tools was 43.10 ± 2.19 in warmer temperatures and 37.98 ± 1.89 in colder temperatures. However, the fatigue decreases significantly for a blacksmith who worked after using the low-cost forging hammer machine (P*<0.05) where the average fatigue score was 33.90 ± 3.21 in warmer temperatures and 28.84 ± 2.92 in colder temperatures.

Based on the result, it also could be seen that cooler temperatures also lower the fatigue significantly (t = 3.335, p<0.05).

**Table 6:** Data on musculoskeletal complaints before using both conventional and low-cost forging hammer machines (post-test) (n=30).

| Descriptions | Conventional tools | | | Low-cost forging hammer machine | | | P* |
|---|---|---|---|---|---|---|---|
| | Mean | SD | p | Mean | SD | p | |
| Pre-test room temp 36-37$^{o}$C (fatigue) | 43.10 | 2.08 | 0.167 | 33.90 | 3.21 | 0.366 | 0.001 |
| Pre-test room temp 27$^{o}$C (fatigue) | 37.98 | 1.89 | 0.151 | 28.84 | 2.92 | 0.333 | 0.001 |

p = Significance for normality, P* = Significance for comparability

### *3.5. Work Productivity*

Tables 7 and 8 shows that the value (p) of productivity in the group using conventional tools and a forging hammer machine has a p-value greater than 0.05, indicating that the two data sets are normally distributed. For one work process, the average production results reach 10 + 0.31 pieces with an average working time of 4 + 0.18 hours (table 8). According to the findings of the study, the productivity of craftsmen before and after using a forging hammer increases by an average of 23.9% (physiological productivity).

**Table 7:** Physiological productivity data from blacksmith (n=30).

| Descriptions | Conventional tools | | | Low-cost forging hammer machine | | | P* |
|---|---|---|---|---|---|---|---|
| | Mean | SD | p | Mean | SD | p | |
| Productivity from the physiological aspect (unit/hour bpm) | 0.0263 | 0.0028 | 0.5651 | 0.0326 | 0.0081 | 0.3777 | 0.001 |

p = Significance for normality, P* = Significance for comparability

**Table 8:** Comparison of average production unit per-hour using low-cost forging hammer machine.

| Groups | N | Production average (unit/hour) | SD | Average different (unit/hour) | *t* | p |
|---|---|---|---|---|---|---|
| Conventional tools | 30 | 3.59 | 2.62 | -163.07 | -50.4 | 0,001 |
| Low-cost forging hammer machine | 30 | 10.28 | 1.21 | | | |

SD = standard deviation

### *3.6. Discussions*

According to the result, this study found an improvement in terms of lower workload, fatigue, and musculoskeletal complaints after using low-cost forging hammer machines rather than conventional tools. Blacksmiths from the Gubug villages obtained an average of until ± 120 beats per minute while working using conventional tools, which means it includes in the category of high-moderate workload [7,8], indicating an increase in workload from the light workload category to the high-medium workload category. Furthermore, the low income earned by craftsmen, which is around Rp. 50,000 or 3.48 USD per day, preventing them from improving their standard of living. This is also because the level of education and skills is still relatively low. On the other hand, the results of forging iron with a hand hammer or conventional tools cannot be maximized, in terms of flatness, size accuracy, and uniformity. Thus, blacksmith must continue to spend a lot of energy and concentration when using conventional tools to achieve the specified size. According to the findings of 30 workers' observations, the percentage of skeletal muscle complaints and general fatigue after working at blacksmith craftsmen in the village of Gubug Tabanan is as follows:

**Table 9:** The top five percentage of musculoskeletal complaints from blacksmith.

| No | Types | Before work (%) | After work (%) |
|---|---|---|---|
| 1 | Backpain | 0,00 | 85,71 |
| 2 | Pain in the right arm | 0,00 | 57,14 |
| 3 | Pain in the left arm | 0,00 | 48,30 |
| 4 | Pain in the waist | 10,29 | 71,43 |
| 5 | Pain in the right leg | 9,29 | 57,14 |

**Table 10:** The top five percentages of fatigue in general from blacksmith.

| No | Types | Before work (%) | After work (%) |
|---|---|---|---|
| 1 | Headache | 14,29 | 71,43 |
| 2 | Tired all over body | 0,00 | 85,71 |
| 3 | Desire to lie down | 14,29 | 100,00 |
| 4 | Stiff all over body | 14,29 | 57,14 |
| 5 | Shoulder stiff | 0,00 | 71,43 |

This study's findings are consistent with previous study from Yusuf and his colleagues [10], who found that having an awkward working position for a long period of time may cause further musculoskeletal disorder (MSD), particularly waist, arm, and low back pain. This MSD issue has the potential to reduce working production by up to 38.7 %. Furthermore, previous research has found that workers with long-term MSD issues are more likely to encounter prolonged work disability and find it more difficult to return to work after some period of absence if workers psychological well-being is poor [11]. According to Dickens and his colleagues [12] and Ervasti and his colleagues [13], workers with MSDs are also more likely to experience depression or anxiety as a result of their conditions. On the other hand, the most common fatigue, such as headaches caused by a dark working environment and shoulder stiffness due to repetitive movement with a traditional hammer obtained from blacksmiths, can significantly reduce work performance and satisfaction [14,15]. Therefore, to overcome this condition, the blacksmith's work process must be immediately improved; otherwise, the incorrect way of working can result in a variety of complaints after work and a decrease in work productivity. One approach that can be taken to address this is to incorporate ergonomic principles into the design of low-cost forging hammer machines, allowing the blacksmith to work naturally, effectively, safely, and comfortably.

## 4. Conclusions

Based on the result and discussion, the low-cost forging hammer machine could significantly decrease the blacksmith’s workload, fatigue, and musculoskeletal complaints while increasing productivity (all tests have p-value <0.05). When compared to conventional tools, the use of the proposed low-cost forging hammer machine can significantly increase work productivity by 23.9%, implying that the iron forging process using the proposed machine is much better and faster. In terms of working environment, according to paired t-test results, working at a cooler temperature (27$^{o}$C) could reduce the workload, fatigue, and musculoskeletal complaints of the blacksmiths [6,9]. In other words, a better working environment may reduce the blacksmith's risk of developing a health problem. However, there is a limitation to this study in that the room temperature at the workplace fluctuated over time, which could have an influence on the blacksmith's working conditions during the observation. Furthermore, the room temperature sensor was not located exactly near the blacksmith, which may have resulted the temperature felt by the blacksmith was differ from the temperature reading since they sit near a source of heat.

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