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Design of Sand Smoothing Tool with Anthropometry Approach to Improve Productivity at CV Karya Gemilang Teknik

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ABSTRACT

The efficiency of the silica sand refining process significantly affects the quality of metal casting at CV Karya Gemilang Teknik, Sidoarjo. Currently, the company performs sand refinement manually, which leads to excessive processing time, inconsistent results, and operator fatigue. This study aims to design an ergonomic sand-refining machine using an anthropometric approach to improve both operator comfort and production productivity. A combination of field observation, anthropometric data collection, ergonomic design analysis, and prototype testing was employed. The key anthropometric parameters considered were standing shoulder height and arm reach, analyzed using statistical measures such as mean, standard deviation, and percentile. Based on these results, the optimal machine dimensions were determined at a height of 92.27 cm and a width of 67.5 cm to accommodate the majority of workers. The designed machine applies a hammer mill mechanism with a 1 HP electric motor, steel frame, and V-belt transmission system. Experimental results indicate that the new design significantly reduces sand-refining time, enhances operator posture and comfort, and produces finer and more uniform sand particles. Consequently, the proposed ergonomic design contributes to improved efficiency, consistent product quality, and higher productivity in the casting process at CV Karya Gemilang Teknik.

1. Introduction

CV Karya Gemilang Teknik is located in a small industrial area with strategic access, facilitating the distribution of raw materials and the delivery of finished products to customers. The CV's location in Sukodono District, Sidoarjo Regency, features a production workshop equipped with a covered work area and a front yard for goods entry and exit. CV Karya Gemilang Teknik produces engineering components from bronze, brass, and aluminum through a metal casting process. These products are widely used in the heavy equipment, machine components, and civil engineering industries. One critical process affecting the quality of castings is the processing of silica sand used in molds. The sand must have a fine and uniform grain size to produce a good surface finish [1].

In CV Karya Gemilang Teknik's production process, silica sand is one of the primary materials used in the manufacture of casting molds. Initially, the silica sand is stored in large lumps in sacks before further processing. Through a refining process, the sand is processed into finer and denser grains, allowing it to be used to fill molds tightly [2]. The refined silica sand is then utilized in the metal mold manufacturing process, where the sand's fineness and density significantly impact the quality of the castings produced [3]. Therefore, proper management of silica sand, from storage to the refining process, is a crucial step in supporting the effectiveness and quality of production at this company.

The Operation Process Chart (OPC) below illustrates the metal mold production flow from pattern creation to final inspection; the primary focus of this thesis is the cleaning process (O-7). After the molding stage (O-5), which causes the silica sand to bond and compact to form the initial geometry, O-7 has a recorded operating time of approximately 25-30 minutes, consistent with field measurements of the manual process performed by the operator. This cleaning process is crucial for the dimensional quality, surface neatness, and structural integrity of the newly solidified material; suboptimal cleaning can potentially leave pores or deformations that will increase the level of defects in subsequent painting, curing, and

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inspection stages. Therefore, making O-7 the focus of research allows for an in-depth analysis of techniques, work sequences, tool parameters, and cleaning duration to reduce defects, improve the consistency of post-cast silica sand solids, and increase the efficiency and quality of the final product.

The silica sand refining process is a crucial step before the sand is used in the molding process. Coarse or contaminated sand can degrade the surface quality of the casting and even cause product defects such as porosity or imperfections [4], [5]. Therefore, the effectiveness of the sand refining process is crucial is a key focus in efforts to increase company productivity. The metal casting production process for bronze, brass, and aluminum materials carried out by CV Karya Gemilang Teknik still faces challenges.

In the production process at CV Karya Gemilang Teknik, one of the most time-consuming stages is manual sand refining. This process is carried out without the aid of mechanical aids, relying entirely on the workers' physical strength. As a result, the time required to complete one bag of sand is quite high and varies among workers. Based on the results of working time measurements of four workers, the average process time ranged from 25 to 30 minutes per bag. This indicates potential inefficiencies in the current work system. This condition indicates variations in the sand refining process time carried out manually by each worker.

The sand refining machine designed in this study is an ergonomically-based tool focused on operator comfort, process efficiency, and increased productivity [6], [7]. This machine has main components: a frame, rotor, hammer, silica sand collection funnel, pulley, and a dynamo as the main drive. The crushing process is carried out mechanically using a hammer mill driven by a dynamo, with power transmitted via a V-belt and pulley. Coarse silica fed into the hopper is crushed by the rotary motion of the rotor and hammers into fine particles, which are then channeled to the final container. In addition to technical performance, this machine is also designed taking into account worker anthropometric data, such as standing shoulder height and arm reach, resulting in a more ergonomic working position and reduced fatigue. The frame height and hopper (inlet hopper) position are adjusted so that workers do not have to bend or lift overhead when pouring material. The overall dimensions of the machine are also compact for easy transportation and storage in limited work areas.

The novelty of this research lies in the integration of the hammer mill's mechanical system with an ergonomic approach in the design of a silica sand refiner for the small-scale foundry industry. Unlike previous designs that focused solely on the technical performance of the machine, this research incorporates operator comfort and safety as key design parameters. This innovation allows for increased process efficiency while reducing fatigue, directly impacting the quality of the refinery results and overall productivity. Furthermore, the choice of manganese steel for the crusher components offers superior durability and consistency compared to conventional designs.

Based on the background described, the researchers propose designing a sand grinding machine specifically for this process Refining. This new machine is expected to improve the quality of finer sand and reduce the time required for the refining process. This will make the production process more efficient and the results more consistent. The design of this refining tool will be discussed with the owner for adjustments to ensure optimal function, taking into account the existing production capacity at the site.

2. Research methods

The research method used is a case study based on the phenomena that occurred in the field, namely CV Karya Gemilang Teknik, including field observations, anthropometric data collection, ergonomic design analysis, and prototype testing [8]. The research began by observing the phenomena and conducting observations in the field, namely at CV Karya Gemilang Teknik, Sidoarjo. This study aims to design an ergonomic sand smoothing machine using an anthropometric approach to increase operator comfort and production productivity. The anthropometric parameters considered are standing shoulder height and arm reach, which are analyzed using statistical measures such as mean, standard deviation, and percentile. The following Figure 1 displays the flowchart in this study [8].

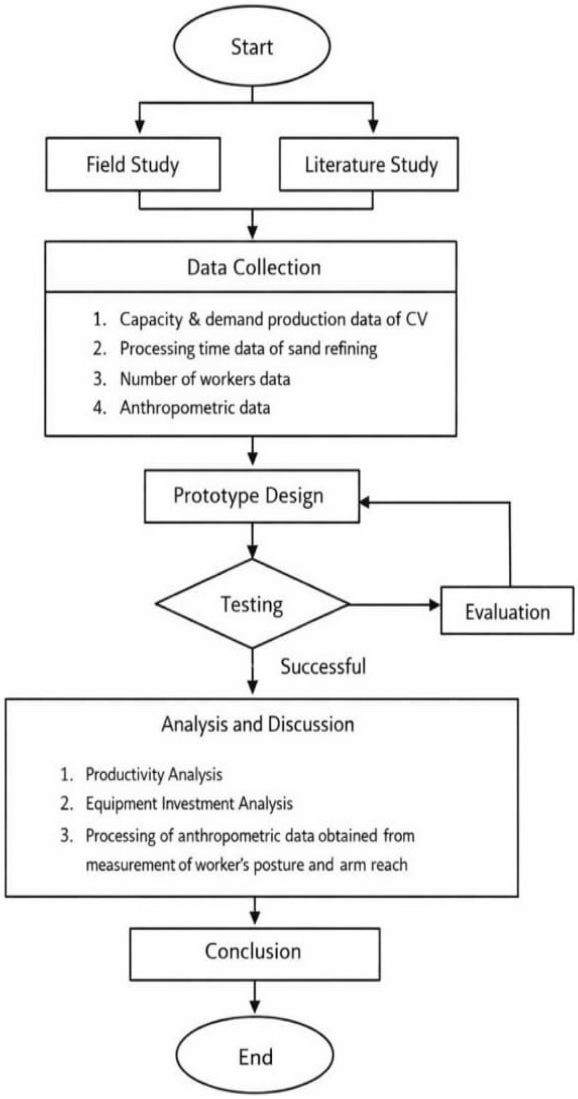

Figure 1 Research flowchart

2.1 Field Study

Field studies are the initial stage of research conducted to obtain a realistic picture of the actual conditions at the research location. At this stage, researchers conduct direct observations of the production process, equipment conditions, and work methods used by workers. The primary objective of field studies is to identify potential problems, obstacles, and opportunities for improvement within the existing work system [9]. The results of field studies serve as the basis for determining the research focus and the direction of tool design that meets field needs.

2.2 Problem Identification

The problem identification stage is carried out after collecting information through field studies. At this stage, researchers review and analyze various problems found in the field, such as inefficient work processes, long production times, or excessive use of human labor. This process is important to ensure that research focuses on the main root causes that have a significant impact on productivity and the quality of work results [9]. Thus, problem identification becomes the basis for formulating research objectives and the direction of technical solution development.

2.3 Data Collection

This stage aims to obtain quantitative and qualitative data that supports the results of problem identification. Data collected include production capacity, processing time, number of workers, and the operational conditions of the equipment used. In this study, one of the main data collected was production capacity data at CV Karya Gemilang Teknik. This data serves as the basis for conducting productivity analysis and determining the need for performance improvements through the design of more efficient equipment [9]. Data collection was carried out systematically through direct observation, interviews, and process measurements in the field.

2.4 Anthropometric Measurements

Anthropometric measurement is the process of collecting human body dimension data used to ensure that the designed tool is ergonomic and fits the user's physical characteristics. This data includes various body measurements such as height, arm length, hand reach, and ideal working position [9]. The goal of this stage is to create a tool design that is comfortable, safe, and efficient for the operator so as to reduce the risk of injury and increase work productivity. The anthropometric measurement data are shown in Table 1 below.

Table 1
Anthropometric Measurements

No	Respondent's name	Measured data		Percentile		
		Standing shoulder height	Hand reach	5th	50th	95th

2.5 Tool Design

After obtaining data supporting the problem, the researcher then designed the tool by creating a related tool design with the aim of solving the problems that occurred in the field. The proposed tool design will be discussed with relevant sources related to the related tool [10]. This tool uses a hammer mill made of strong and durable manganese steel. This tool uses a hammer mill made of manganese steel because this material has high wear resistance and impact strength, so it is able to withstand repeated impacts from the process of crushing hard silica sand. In addition, manganese steel has unique working properties, namely becoming harder when deformed or impacted, so it is ideal for use on components exposed to friction and intensive impacts. The selection of this material aims to extend the service life of the tool, reduce the frequency of maintenance, and maintain the consistency of the size of the sand grains produced [11]. The proposed tool design is shown in Figure 2 and Figure 3.

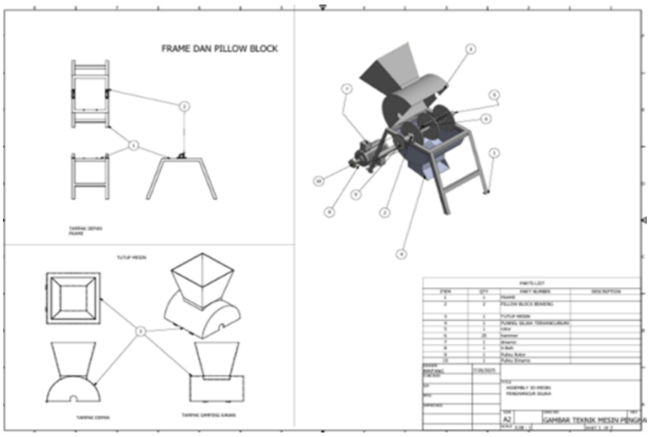

Figure 2 Overall Tool Design

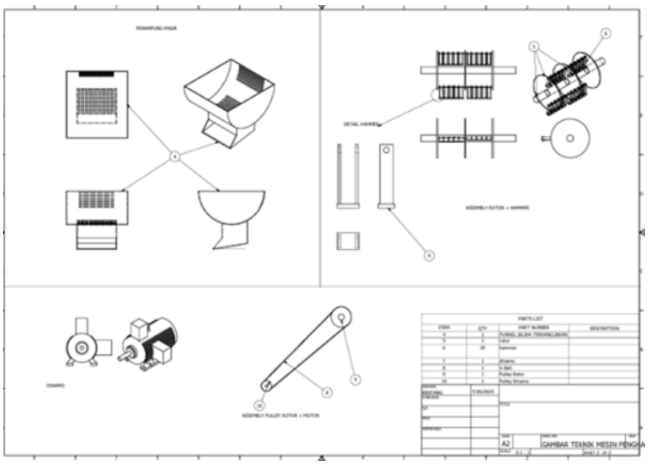

Figure 3 Design of Tool Design for Each Part

2.6 Tool Testing

The tool testing phase is carried out after the tool design and manufacturing process is complete. The main objective of this phase is to assess the tool's performance, effectiveness, and efficiency under actual operational conditions. Testing includes evaluating process time, product yield, operator comfort, and the level of tool safety. If the test results indicate a discrepancy with the planned specifications, adjustments or modifications to the design are made until the tool functions optimally according to user needs and field conditions. This phase serves as the final verification of the design's success before the tool is fully implemented.

3. Results and Discussion

3.1 Anthropometric Calculations and Standard Deviation

Anthropometric data of employees at CV Karya Gemilang Teknik was collected through direct measurements of four workers involved in the feed production process. The results of these measurements will be analyzed and used as a basis for designing machines that comply with ergonomic principles [12], [13], [14]. The types of measurements and their purposes are presented below as a guide in the data collection process. In this uniformity test, the average calculation and standard deviation were calculated. The following Tables 2 and 3 show the results of these calculations:

Table 2
Research data

No	Name	TBB	JT
1	Angga	98	73
2	Budi	96	77
3	Yuda	97	72
4	Huda	94	79
Average		**96.25**	**75.25**
Standard Deviation		**1.70783**	**3.30404**
	∑XI	385	301
	(∑XI)²	148225	90601
	∑XI²	37065	22683

With the formula description:

$$\text{Average} = \frac{\sum X}{N}$$

$$\text{standard deviation} = \sqrt{\frac{1}{n-1}\left(\sum X_i^2 - \frac{(\sum X_i)^2}{n}\right)}$$

$$\Sigma XI = X_1 + X_2 + X_3 + X_4$$

$$(\Sigma XI)^2 = (X_1 + X_2 + X_3 + X_4)^2$$

$$\Sigma XI^2 = X_1^2 + X_2^2 + X_3^2 + X_4^2$$

3.2 Data Adequacy Test

Before further analysis, the anthropometric measurement data must be tested for adequacy to ensure that the collected data is statistically representative of the population. The data adequacy test aims to determine whether the sample size is sufficient to ensure the data processing results are valid and do not require additional respondents. This will ensure that the tool design results reflect actual conditions in the field and support the optimal application of ergonomic principles.

SSH (Standing Shoulder Height)
N = 4
S = 1,70783/96,25 = 0,033 = 3,3%
 = 100% - 3,3% = 96,7% → K = 2

$$N' = \left[\frac{\frac{2}{0,033}\sqrt{4(37065)-(148225)}}{385}\right]^2 = 3,03$$

N' < N = Then the data is sufficient

HR (Hand Reach)
N = 4
S = 3,304 /75,25 = 0,043 = 4,3%
 = 100% - 4,3% = 95,7% → K = 2

$$N' = \left[\frac{\frac{2}{0,043}\sqrt{4(22683)-(90601)}}{301}\right]^2 = 3,13$$

N' < N = Then the data is sufficient

3.3 Data Adequacy Test

Before being used in designing tool dimensions, anthropometric measurement data needs to be tested for uniformity to ensure that the obtained values have a consistent distribution and are representative of the worker population. This uniformity test is conducted to determine whether the collected data is still within statistical control limits, so that it can be used as a valid basis in the ergonomic design process. Non-uniform data can lead to errors in determining tool sizes, which ultimately has the potential to reduce operator comfort and work safety. Therefore, this uniformity test stage is a crucial initial step before further analysis of anthropometric data.

SSH (Standing Shoulder Height)
BKA : 96,25 + (2 x 1,70783) = 99,666
BKB : 96,25 - (2 x 1,70783) = 92,834

Table 4
SSH data uniformity

SSH	Average	Upper Limit (UCL)	Lower Limit (LCL)
98	96.25	99.666	92.834
96	96.25	99.666	92.834
97	96.25	99.666	92.834
94	96.25	99.666	92.834

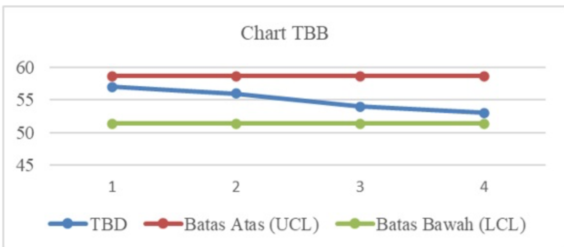

Figure 4 SSH Graph

After conducting a uniformity test on the SSH data in Table 4, the next stage is to analyze the uniformity of the JT data shown in Table 5. This test aims to ensure that the hand reach measurement data has a consistent distribution and there are no extreme values that can affect the accuracy of the tool design. Uniform data indicates that variations between respondents are still within reasonable limits and can be used as a basis for calculating the ergonomic dimensions of the tool [15]. Thus, the results of the JT data uniformity test become an important reference in ensuring that the tool designed is in accordance with the physical characteristics of users in the field.

HR (Hand Reach)
BKA : 75,25 + (2 x 3,30404) = 81,858
BKB : 75,25 - (2 x 3,30404) = 68,642

Table 5
HR data uniformity

HR	Average	Upper Limit (UCL)	Lower Limit (LCL)
73	75.25	81.858	68.642
77	75.25	81.858	68.642
72	75.25	81.858	68.642
79	75.25	81.858	68.642

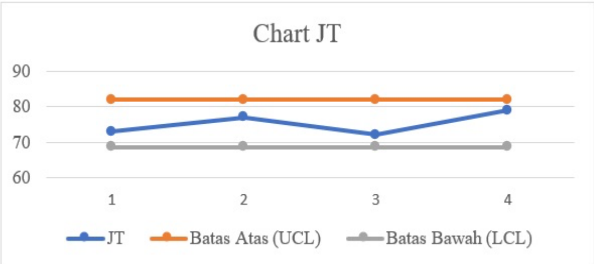

Figure 5 HR Graph Image

From the data described above, it can be seen that no data falls outside the CL and LCL limits, so the data is said to be uniform. Tables 6 and 7 show the calculation and selection of percentiles.

Table 6
Percentile Calculation

Persentil	Rumus
1	$\bar{X}$ - 2,325 x σ
2,5	$\bar{X}$ - 1,96 x σ
5	$\bar{X}$ - 1,645 x σ
10	$\bar{X}$ - 1,28 x σ
50	$\bar{X}$
90	$\bar{X}$ + 1,28 x σ
95	$\bar{X}$ + 1,645 x σ
97,5	$\bar{X}$ + 1,96 x σ
99	$\bar{X}$ + 2,325 x σ
$\bar{X}$	Σ
96,25	170,783
75,25	330,404

Table 7
Percentile Selection

No	Antrophometri	
	SSH	HR
1^{th}	92.2793	67.5681
2^{th}	92.9027	68.7741
5^{th}	93.4406	69.8149
10^{th}	94.064	71.0208
50^{th}	96.25	75.25
90^{th}	98.436	79.4792
95^{th}	99.0594	80.6851
97.5^{th}	99.5973	81.7259
99^{th}	100.2207	82.9319

The use of the first percentile in selecting anthropometric data reflects the characteristics of the majority of the population without being affected by extreme values. In the context of ergonomic design, such as standing shoulder height and hand reach, the use of percentiles allows for the design of tools that are more inclusive and fit the posture of the majority of users. This is important to ensure comfort and work efficiency, particularly in the design of silica sand grinders.

3.4 Determination of Main Dimensions of the Tool

The main dimensions of the tool are determined based on the worker's anthropometric data to ensure the resulting design is ergonomic and appropriate for the user's posture and reach. This approach aims to ensure that the tool can be operated comfortably without causing excessive fatigue or unnatural working postures.

The height of the table or the main position of the machine is determined based on the operator's standing shoulder height, allowing the operator to operate the tool without having to bend over. Based on measurements, the maximum standing shoulder height for workers is 92.27 cm, so the tool height is designed to be no higher than 92.27 cm. This value is selected using the first percentile, ensuring that all workers, even those with the shortest stature, can still operate the machine easily and safely.

Meanwhile, the depth of the work area is determined based on the forward arm reach, ensuring that all parts of the tool can be reached without excessive stretching. Based on the anthropometric measurements, the depth of the work area, or machine width, was determined to be 67.5 cm. This dimension was chosen to allow the operator to access the entire work area efficiently, while maintaining comfort and safety during machine operation.

3.5 Tool Design and Tool Function Analysis

Based on observations and data collection conducted at CV Karya Gemilang Teknik, as well as interviews with the owner to support productivity and quality improvement in production, a sand smoothing tool design was developed that was mutually agreed upon by the researcher and the informants. Figure 6 shows the tool design used in this study.

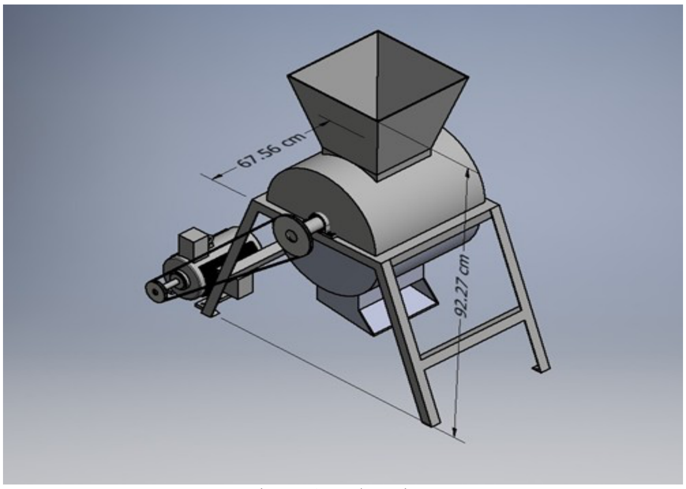

Figure 6 Tool Design

From the results of anthropometric calculations, it is known that the dimensions of the machine to be designed have a width of 67.56 cm and a total height of 92.27 cm. This size is adjusted to the standing shoulder height and forward arm reach data of the workers, so that the machine can be operated comfortably without causing excessive fatigue [14], [15], [16], [17]. This design considers the 1st to 95th percentiles, to accommodate most users and improve efficiency and work safety in the production environment.

Furthermore, the designed sand smoother has been proven to increase the efficiency of the smoothing process time compared to manual methods, while maintaining the consistency of the resulting sand grain size. With its ergonomic, compact, and easy-to-operate design characteristics, this tool has great potential for implementation not only at CV Karya Gemilang Teknik, but also in small and medium-sized business units engaged in metal casting or similar industries to support increased productivity and production quality [14], [18], [19], [20].

4. Conclusion

Based on the research and design results conducted at CV Karya Gemilang Teknik, it can be concluded that an ergonomic hammer mill-based silica sand refiner has been successfully designed and implemented to suit the worker's body size. This tool uses a hammer mill made of manganese steel, which offers high wear resistance and a longer service life. It was designed based on worker anthropometric data, with a machine height of 92.27 cm and a width of 67.5 cm to suit the operator's working posture.

Test results showed that the new tool was able to increase sand refinement process efficiency by 35% compared to manual methods, from an average of 22 minutes to 14 minutes per work cycle. Furthermore, based on observations and interviews, operator comfort levels increased by 40%, indicated by a reduction in physical complaints such as back pain and shoulder fatigue after use. This improvement demonstrates that the application of ergonomic principles to tool design significantly contributes to worker productivity and well-being.

As a direction for further research, optimization of the tool's production capacity and energy efficiency, as well as testing the durability of the hammer mill material over longer operating periods, are necessary. In addition, further research can integrate vibration sensors and automatic control systems to monitor tool performance in real-time, thereby supporting the implementation of smart ergonomic tool design in small and medium industrial environments.

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