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Experimental Study of Adaptive Jig Development to Facilitate Metal Welding Learning

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ABSTRACT

The advancement of technology within the manufacturing sector continually accelerates, frequently resulting in heightened consumer demand driven by enhancements in product quality, including consistency and quality control. This study endeavors to enhance the production process by leveraging reverse engineering alongside Indonesian anthropometry methods. The findings demonstrate that the resultant products can effectively meet customer requirements, exhibiting durability and resilience against wear and tear. By integrating reverse engineering techniques and Indonesian anthropometry methods into the production process, manufacturers can achieve greater precision and tailor products to better suit consumer needs. This approach not only enhances product quality but also contributes to increased customer satisfaction and loyalty. Furthermore, it underscores the importance of incorporating innovative methodologies to keep pace with the evolving demands of the market and to ensure continued success within the manufacturing industry. As technology continues to advance, embracing methodologies like reverse engineering and anthropometry will be crucial for manufacturers seeking to remain competitive and deliver products that surpass consumer expectations in terms of durability, performance, and overall quality.

1. INTRODUCTION

In the Manufacturing 4.0 era, Indonesia's manufacturing industry has experienced notable expansion. The government actively advocates for the adoption of advanced technology and digitalization to elevate product standards and efficiency while streamlining production processes [1]. This approach also encourages data-driven decision-making to bolster overall effectiveness. Furthermore, significant attention is directed towards nurturing a skilled workforce and promoting collaboration between industrial sectors and educational institutions. Such efforts are crucial for adapting to the dynamic landscape of modern manufacturing, ensuring sustained growth, and fostering innovation in Indonesia's industrial ecosystem [1].

In manufacturing, the machining process is very important in the construction, manufacture and formation of a material / product. The process of forming a metal product usually involves cutting, melting, or connecting. One splicing technique that is often used is welding. Welding is one of the manual assembly processes that gives a heat effect to the workpiece to be assembled. Workers often find difficulties in welding, such as frequent workpiece shifts, uncomfortable positions, inappropriate welding results, and difficulties in the process of loading and unloading objects. Another mistake that often occurs during the welding process is the lack of precision of the components to be welded, resulting in defective products. This happens because of errors in designing and selecting tools used as tools to support the workpiece to be welded [2]. The use of production aids will facilitate the processing process, speed up the production process, produce uniform and quality products or components, save production costs and provide a sense of security for operators [2]. Designing a product is an interactive activity by combining science, art and creativity in accordance with the desired needs, where the resulting solution is not unique [3]. The design of assistive devices continues to develop due to the nature of the tools that must be able to meet the manufacturing process. Meanwhile, the design of welding aids can speed up the welding training process because welding demonstration aids are needed to clamp the workpiece according to the welding position of 1G to 4G position plates and 1G, 2G, 5G and 6G welding position pipes [4].

In the manufacturing process, especially in welding activities, the importance of using jigs as a tool cannot be ignored. An effective jig will consist of two main components, namely locating and clamping. Locating plays a role in determining the correct position for the workpiece, while the clamp serves to hold the workpiece from moving or shifting during the welding process. In other words, the jig becomes a key element in ensuring accuracy and stability during the welding process. In this context, researchers realized the urgent need to design a jig that was efficient and reliable in supporting the welding process. The main purpose of designing this tool is to increase productivity, accuracy and safety in welding operations. With the right jig, the operator can easily place the workpiece in the desired position and ensure that it is securely locked during the welding process. In the design steps, researchers will consider various factors, including the type of material to be welded, the shape and size of the workpiece, and the welding method used. It is important that the jigs can be adapted to the specific needs of each welding project. In addition, ergonomic aspects will also be considered so that operators can use the jig comfortably and efficiently [5].

Through the design of this tool, it is expected that the welding process will become more efficient, more accurate, and safer. The end result is improved product quality and operational efficiency in a manufacturing environment. With a focus on innovation and reliability, the design of this jig is a strategic step in improving the performance and competitiveness of the welding industry.

2. LITERATURE REVIEW

2.1 Jigs and fixtures

Jigs and fixtures play a crucial role in manufacturing processes, serving as specialized work-holding and tool-guiding devices that ensure the quality and precision of the output [6]. By using jigs and fixtures, manufacturers can achieve increased production, cost reduction, interchangeability and high accuracy of parts, improved safety, easy machining of complex and heavy components, and consistent quality of manufactured products. In addition to their role in work holding, jigs also guide the tool to its proper location or movement during operation. The use of jigs and fixtures in the manufacturing industry is vital for achieving efficient and effective production processes.

Using jigs and fixtures in the production process provides several advantages. Firstly, it leads to an increase in productivity. By using jigs and fixtures, the production process becomes more efficient and streamlined, resulting in higher output rates. Secondly, jigs and fixtures contribute to cost reduction. By accurately guiding tools and workpieces, jigs and fixtures minimize errors and waste, reducing the need for rework or scrapped parts. Thirdly, jigs and fixtures ensure the interchangeability and high accuracy of parts [7]. This means that each part produced using the same jig or fixture will have consistent dimensions and fit perfectly together. Additionally, the use of jigs and fixtures reduces the need for inspection and quality control expenses [6]. Fourthly, jigs and fixtures enhance the safety of the production process. Operators can work more safely and efficiently with the support of jigs and fixtures, as they provide secure and stable workpiece holding [8]. Lastly, jigs and fixtures enable easy machining of complex and heavy components. The precise and controlled positioning provided by jigs and fixtures allows for easier machining of intricate and heavy parts, resulting in accurate and high-quality finished products. Furthermore, the use of jigs and fixtures leads to the automation of machine tools to a significant extent [9]. This automation reduces the need for manual labor and increases efficiency in the production process. In summary, the advantages of using jigs and fixtures in the production process include increased productivity, cost reduction, interchangeability and high accuracy of parts, reduction of inspection and quality control expenses, improved safety, easy machining of complex components, and automation of machine tools. These advantages make jigs and fixtures an indispensable tool for manufacturers seeking to optimize their production processes and achieve consistent quality in their products [10]. The use of jigs and fixtures in the production process provides numerous advantages. These advantages include increased productivity, cost reduction, interchangeability and high accuracy of parts, reduction of inspection and quality control expenses, improved safety, easy machining of complex components, and automation of machine tools [11]. All in all, the use of jigs and fixtures plays a crucial role in improving productivity, reducing costs, ensuring high accuracy and interchangeability of parts, improving safety, enabling easy machining of complex components, and automating machine tools in the production process. The use of jigs and fixtures in manufacturing has numerous advantages, including increased productivity, cost reduction, interchangeability and high accuracy of parts, reduction of accidents and safety incidents, easy machining of complex and heavy components, and consistent quality of manufactured products. Overall, the use of jigs and fixtures in manufacturing provides a wide range of benefits, including increased productivity, cost reduction, improved safety, easy machining [12].

2.2 Reverse engineering

Reverse Engineering (RE) involves the acquisition of 3D geometry data through metrology techniques, followed by data manipulation using specialized software to produce usable information [13]. This process facilitates the development of 3D models (known as digital threads) for End-of-Life (EOL) parts, enabling a digitally guided approach to manufacturing, inspection, and marketing [14, 15].

In the manufacturing sector, the incorporation of reverse engineering into the digital chain within Product Lifecycle Management (PLM) presents various social and economic challenges. These encompass shorter development cycles, leading to notable cost savings and streamlined knowledge management concerning the project [16].

Reverse engineering is a process that involves taking apart and analyzing a device or program to understand its inner workings, with the aim of reproducing or improving upon the original design [17]. During the process of reverse engineering, one must carefully examine and analyze the components, functions, and algorithms used in the device or program [18]. The concept of the reverse engineering method involves disassembling a product to understand how it was made and how it works. This process can be used to gain insight into the design and functionality of a product and can be especially useful for understanding legacy systems or products with incomplete documentation [19, 20]. Reverse engineering often involves using tools such as disassemblers, decompiles, and debuggers to analyze the code and behavior of the product.

This method can be applied to hardware, software, or a combination of both and is used in various fields such as software development, industrial design, and intellectual property protection [21].

2.3 Ergonomic

With the increasing emphasis on ergonomics, additive manufacturing (AM) has found widespread application across various domains concerning product and prototype design. These include fields such as medicine, the development of assistive technologies (AT), wearable technologies (WT), and physical human-machine interfaces (pHMI) [22]. Ergonomics aims to guide the creation of products and tasks that are safe, comfortable, and efficient, drawing from the study of human characteristics and interactions with machines and the environment. Consequently, product development based on ergonomics typically involves an iterative process of design, evaluation, and redesign, incorporating multiple modifications based on user feedback from prototypes. As user evaluations are ideally conducted on full-size physical prototypes made from near-final materials, AM emerges as an ideal technology for manufacturing prototypes for ergonomic testing. This is especially relevant for applications requiring customized fits for humans and for iterative testing and redesign processes [23].

The ergonomic method used in the study [24] is the Forces ergonomic method. This method involves capturing movement at the workstation, applying the Forces method to assess the initial risk, and recalculating the kinetics considering the external forces applied by the exoskeleton on the body [25]. The Forces method is designed to be software-automated, allowing for agile generation of results. It serves as a predictive tool for decision-making regarding the suitability of exoskeletons prior to their implementation in workstations.

"In the article discussing the latter manufacturing option, the work of Concli et al. [26] is referenced. Although the ergonomic methods used in their study are not specifically described, the research emphasizes the importance of understanding complex system interactions. Similarly, this study on bus drivers' mobile phone use employs a sociotechnical systemic analysis approach. This approach explores how various factors—such as destinations, people, infrastructure, technology, culture, and processes—interact and influence driver behavior with regard to mobile phone use while driving [27]. "In addition, the study also involved an online survey of bus drivers to understand the extent to which cell phone use occurs and the habits of bus drivers in using mobile phones. Although specific ergonomic methods are not described, the study provides valuable insight into the sociotechnical factors that underpin the use of mobile phones by bus drivers [28].

The ergonomic methods used in this study include exploratory conventional content analysis. The study used individual interviews and focus group discussions to identify perceived barriers related to the practical implementation of ergonomics knowledge transfer to small and medium-sized enterprises in Iran. Inductive content analysis is used to analyze data and categorize identified bottlenecks [29].

2.4 Anthropometry

Anthropometry is the scientific study of human body measurements and proportions. It involves taking various physical measurements of an individual, such as height, weight, waist circumference, and body fat percentage, to assess their body composition and overall health [17].

Utilizing anthropometry in equipment design minimizes the risk of injury and enhances productivity and efficiency. Crafting tools and systems tailored to the user decreases the probability of user error and the necessity for corrective measures, thereby potentially boosting productivity and efficiency [30].

Anthropometry plays a crucial role in understanding the relationship between human body measurements and various health outcomes [31]. By using anthropometric measurements, researchers and healthcare professionals can gain valuable insights into the prevalence of obesity, assess an individual's risk for certain health conditions such as cardiovascular disease or diabetes, and monitor changes in body composition over time [32, 33]. Anthropometry is also essential in the field of product design and ergonomics. It allows for the creation of products that are better suited to the dimensions and proportions of the human body, enhancing comfort and usability [33]. For JIG PRODUCTS, incorporating anthropometry into the design process can lead to the development of products that cater to a wider range of consumers, considering diverse body types and sizes. This approach ensures that JIG PRODUCTS are not only functional but also inclusive, offering a better user experience for all individuals [19].

3. METHODOLOGY

3.1 Research design

This research will be conducted through several stages to develop an adaptive jig that can facilitate metal welding learning using two main approaches: reverse engineering and anthropometry. The stages of the research include literature study, data collection, data processing, discussion, and conclusion.

(1) Literature Study

The literature study is carried out by reviewing and understanding theories and concepts related to welding jig design, reverse engineering, and the application of anthropometry in the design of industrial aids. The literature used will include books, scientific articles, conference papers, and other reliable sources. This study aims to provide a theoretical foundation on the importance of ergonomic and effective jig design in improving welding performance and comfort.

(2) Data Collection

Data collection is carried out through two main approaches: qualitative and empirical, focusing on existing welding jig designs and the application of anthropometry to design a new jig.

Qualitative Data: Qualitative data will be collected through interviews with welding jig users and direct observations of existing welding aids. Interviews aim to uncover the challenges faced by users when using the current tools, such as difficulties in moving the jig, instability of the workpiece during welding, and discomfort in using the tool. Observations will be made to assess the performance of the existing tools and identify areas for improvement.

Empirical Data: Empirical data will be gathered through experimental trials involving the use of the adaptive jig by welding training participants. Data collected will include:

- Performance Observations: Observing the effectiveness of the jig in helping participants achieve the correct welding position and accuracy in welding tasks.
- User Feedback: Participant evaluations on the comfort and effectiveness of the designed adaptive jig were collected through interviews or questionnaires.

(3) Data Processing and Analysis Techniques

The collected data will be analyzed using a qualitative approach appropriate for the research objectives:

Qualitative Analysis: Interview and observation data will be analyzed using thematic analysis to identify key themes and patterns related to user experiences with the current welding jig. This analysis will also help understand the user's needs when designing a more ergonomic and functional adaptive jig.

Reverse Engineering: The reverse engineering method will be used to analyze the existing welding jig designs. This process will involve disassembling the existing jig to understand its components and functions, as well as identifying the weaknesses in the current design. The results from the reverse engineering analysis will be used to design a new, more efficient, and ergonomic jig.

(4) Discussion

In this stage, the researchers will interpret the results of the data analysis and discuss the effectiveness of the adaptive jig in improving metal welding learning. The discussion will include:

- Comparison with Previous Studies: Comparing the findings of this research with existing studies related to welding jig development and the application of anthropometry.
- Advantages and Disadvantages of the Adaptive Jig: Assessing the strengths and weaknesses of the adaptive jig design based on the findings from the experiments and user interviews.
- Recommendations for Future Research: Offering recommendations for future studies, particularly in developing more ergonomic, efficient, and accessible welding aids.

(5) Conclusion

The conclusion will summarize the main findings of the research, highlighting the contribution of the adaptive jig design to improving metal welding education. The conclusion will also reflect on the limitations of the study, such as sample size or methodology, and provide recommendations for future research in welding.

3.2 Methodological approach

This research combines two main approaches in the design of the adaptive welding jig:

(1) Reverse Engineering

The reverse engineering technique is used to analyze the existing welding jig designs by disassembling and evaluating the components of the jig. The results from this analysis provide insights needed to design a more efficient and suitable jig for welding tasks.

(2) Anthropometry

Anthropometry is used to ensure that the adaptive jig design is suited to the average body dimensions of Indonesian users. By considering relevant anthropometric variables, the jig is designed to be more ergonomic, comfortable to use, and reduce the risk of injury during operation.

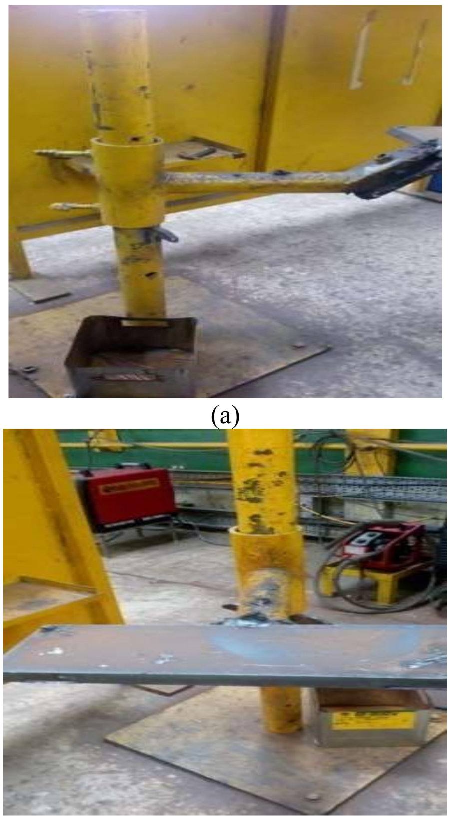
The methods used are reverse engineering and anthropometry.

4. DATA COLLECTION AND CALCULATION

4.1 Data collection

The data collected to perform reverse engineering was obtained from interviews with tool user operators and direct observation by looking at welding aids that exist today. Interviews are conducted to accommodate the aspirations, ideas and ideas of respondents, who will be evaluated to get a meeting point of ideas. The list of questions asked of respondents refers to research conducted [20]. The following questions and the summarized responses from respondents provide a concrete answer: The first question is whether the current research aids have issues and what the constraints of the tools being used are. The responses indicate that the primary obstacle is the lack of mobility of the auxiliary equipment. If the object to be welded has a large enough dimension, it is difficult to bring it to the tool.

Additionally, the objects being welded often shift because there is no clamp to secure them in a fixed position. The small size of the welding table only supports welding small objects and is primarily suited for flat plates. Welding objects in the form of tubes or cylinders is particularly challenging.



(a)

(b)

Figure 1. (a) side view of the actual product (b) isometric view of the actual product

The second question is: What kind of tools are expected? The response indicates that the desired tool should be mobile (portable) and capable of accommodating both plate and cylinder welding.

The third question is: If there were a portable welding tool that supports the welding process for both plates and cylinders and is designed to suit the body size of Indonesians, what would your response be? The feedback indicates that such a tool is highly anticipated by users of welding equipment. This can be illustrated by the designs of the welding aids currently in use.

So, it can be concluded that based on descriptive analysis from the interview results, mobile welding aids are needed to assist in gripping plates or cylinders. The current display of assistive products can be seen in Figure 1. The Indonesian anthropometry data were incorporated into the design of the adaptive jig by referencing a national database of body measurements for the average Indonesian population. Specifically, measurements such as average arm length and shoulder width were used to adjust the jig's dimensions to meet the ergonomic needs of Indonesian workers, see Table 1.

Table 1. The Indonesian anthropometry data

Dimensions	Description	5th	50th	95th	SD
D1	Height	116.68	152.06	187.45	21.51
D2	Eye height	107.42	141.74	176.07	20.87
D3	Shoulder height	95.97	126.37	156.77	18.48
D4	Elbow height	72.77	95.3	117.83	13.7
D5	Hip height	54.49	86.93	119.37	19.72
D6	Intervertebral height	48.28	66.19	84.1	10.89
D7	Fingertip height	40.18	60.36	80.54	12.27
D8	Height in a sitting position	60.95	77.73	94.52	10.2
D9	Eye height in a sitting position	50.96	67.53	84.1	10.07
D10	Shoulder height in a sitting position	37.5	54.64	71.78	10.42
D11	Elbow height in a sitting position	10.86	24.66	38.46	8.39
D12	Thigh thickness	3.59	14.63	25.67	6.71
D13	Knee length	37.58	49.52	61.45	7.26
D14	Popliteal length	30.1	39.51	48.92	5.72
D15	Knee height	35.93	47.93	59.93	7.29
D16	Popliteal height	30.88	40.02	49.16	5.56
D17	Shoulder width	26.14	38.62	51.11	7.59
D18	Upper shoulder width	15.13	31.2	47.27	9.77

4.2 Design using the reverse engineering method

The design of metal finishing demonstration aids is carried out using reverse engineering methods. The stages carried out include the disassembly stage, assembly stage, comparison stage or benchmarking stage, new product design stage, selection of the best design, making prototypes, and analyzing design results.

4.2.1 Product disassembly activities (disassembly)

The product disassembly stage aims to know and understand the components that make up the product and know the function of each component.

a) Assembly of Existing Products

Disassembly of existing products is used to determine the function of each part. The current product image can be seen in Figure 2.

After the product is disassembled, the functions of each part become clear. These functions are detailed in Table 2.

4.2.2 Assembly of products on the market

After the product is disassembled, the functions of each part can be identified. The functions of each part of the product currently available on the market are detailed in Table 3.

4.2.3 Product assembly activities (Assembly)

After the product is disassembled, the next stage is the product assembly analysis. This stage is used to benchmark the new products that are to be designed. During this stage, researchers combine components from existing welding aids and those currently available on the market. Figure 3 illustrates the assembly chart of the current product, while the assembly chart of the tools on the market is also presented.

4.2.4 Assembly of existing products

The following are the stages for assembling the current welding aid:

1) The retaining pipe is combined with the retaining base.

2) The welding table tray is inserted into the retaining pipe.

3) The height of the welding table tray is adjusted to suit the operator using the tool, and it is then secured with a locking lever.

The locking base is bolted to the floor to ensure stability and prevent shaking.

The current product assembly diagram can be seen in Figure 4.

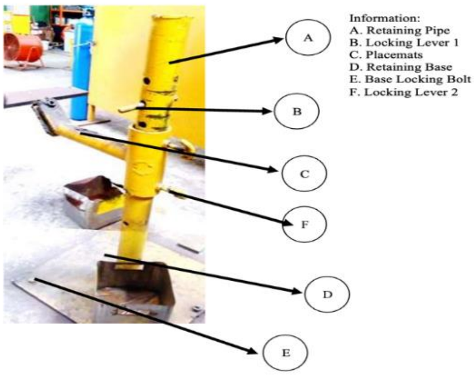


Figure 2. Definition of product parts if disassembled

Table 2. Functions of the current auxiliary part

No	Symbol	Part Name	Function / Criteria
1	A	Retaining Pipe	The original description was vague ("backrest from the tray"). I clarified it by stating that the pipe prevents the tray from moving or shifting during use.
2	B, F	Locking Lever	The previous wording was unclear. I rephrased it to indicate that the locking lever ensures the tray remains stable and prevents shifting during operation.
3	C	Placemats	I clarified that placemats are meant to provide a stable surface to prevent items from shifting.
4	D	Retaining Base	I replaced the vague phrase "when in use" with "secures the tray in position to maintain stability while in use," which is more specific.
5	E	Locking Bolt	The previous description was somewhat incomplete. I added more context, explaining that the locking bolt adjusts the height of the tray and supports workpieces during welding.

Table 3. Functions of auxiliary parts on the market

No	Symbol	Part Name	Function / Criteria
1	A	Chunk	The function was clarified to indicate that it supports workpieces to prevent movement during welding.
2	B	Table	Reworded to specify that it holds workpieces securely during the welding process.
3	C	Table frame	I adjusted the description to clarify that the table frame is part of a stable work area, supporting both the table and the workpieces.
4	D	Place	I rephrased it to indicate that it provides a stable area for positioning objects, ensuring they remain stationary.
5	E	Equipment backlog	Reworded the description to emphasize its role as a working table that also allows for organized storage and easy access to equipment.

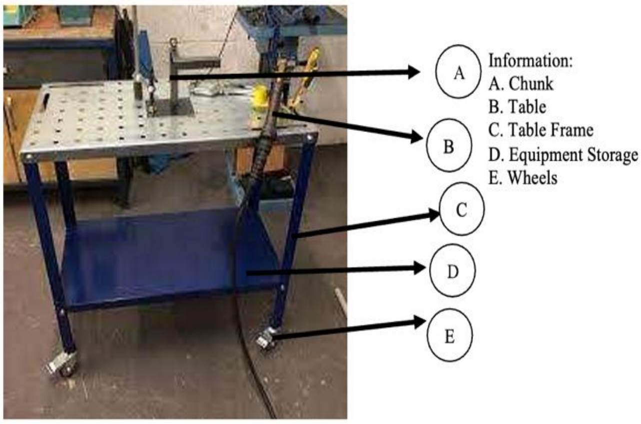


Figure 3. Assembly of products on the market

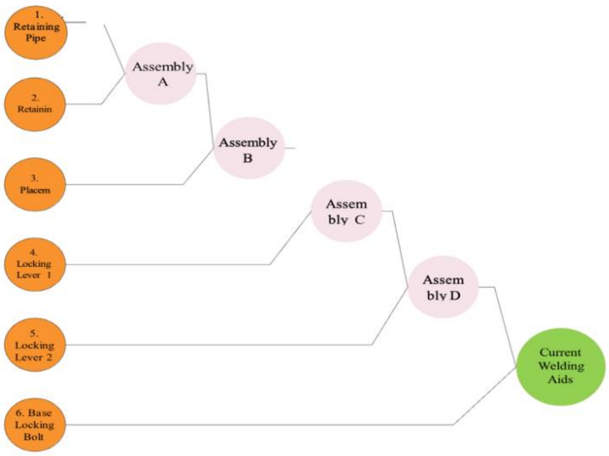


Figure 4. Assembly chart of the current tool

4.2.5 Assembly of products on the market

The following are the stages of the current welding aid assembly, namely:

1) The table frame will be paired with wheels
2) The table frame will be paired with the equipment storage area
3) The table top will be combined with the table frame
4) Chunk will be combined with the table that has been assembled

The assembly of existing products can be seen in Figure 5. The legend of the assembly chart can be seen in Table 4.

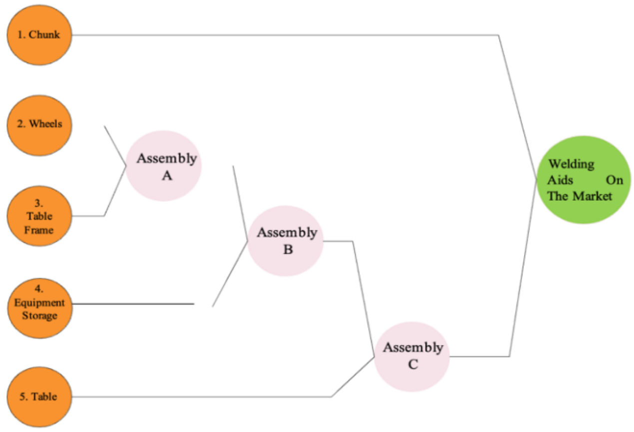


Figure 5. Assembly chart image of tools on the market

4.2.6 Banchmarking

At this benchmarking stage, researchers make observations on existing and existing tools on the market. At this stage there is a comparison between the current design of welding aids with the place of welding aids on the market. By comparing and observing the two equipment, it can be known the weaknesses and advantages of each product. 1. Comparison of Similar Products Comparing similar products is done to find out the weaknesses and advantages of each product. Can be seen at Assembly 1 No Symbol Information Sum Assembly 1 Table 5. is the weakness and advantage of the current welding aids and welding aids on the market. 2. Comparison of Constituent Components Comparison of the constituent components of existing and existing tools on the market can be seen in Table 6.

Table 4. Legend of the assembly tools that exist today

No	Symbol	Information	Sum
1		Component	11
2		Sub Assembly	7
3		Assembly	2

Table 5. A comparison table of the advantages and disadvantages of current and existing welding aids available on the market

No	Comparison	Current Welding Aids	Welding Aids
1	Benefit	Simple design	Assistive devices can be moved around as needed because of the presence of wheels Presence of storage equipment Spacious working table
2	Limitation	The design is fixed, so it cannot be moved because it has been bolted to the floor It has only one placemat to assist with welding, and its size is small It does not conform to anthropometric measurements It can only be used to assist with the welding of plates	It can only be used to assist with welding plates, while welding cylindrical objects is not possible It does not conform to anthropometric measurements. Although it has wheels, the plate gripping aid remains fixed

Table 6. Comparison table current and existing welding aid components on the market

No	Comparison	Current Welding Aids	Welding Aids
1	Table	*X*	*V*
2	Table Frame	*X*	*V*
3	Chunk	*X*	*V*
4	Storage Area	*X*	*V*
5	Equipment	*X*	*V*
6	Wheel	*V*	*X*
7	Retaining Pipe	*V*	*V*
8	Locking Lever	*V*	*V*
9	Placemats	*V*	*V*

5. RESULT AND DISCUSSION

The proposed tool design is presented in both 2D and 3D drawings. Before starting the design process, the necessary components are first defined. The anthropometric variables required for product design can be found in Table 7, and the proposed dimensions for the product design are shown in Table 8.

Table 7. Anthropometric variable length requirements

Activities		Welding Table	Pipe	Chunk
Data Requirements		Table height	Pipe length	Chunk
		Table width		Length
		Table length		
	Variable			
		Elbow height	Body height	Elbow span
Anthropometric		Shoulder length forward hand grip	In subtracted	length
		Elbow span length	Elbow height	

Table 8. Determination of proposal size

Part	Variable Anthropometry	Press Entil	Size (cm)	Final Size after Considerations Load and Slack (cm)
	Welding Table			
Welding Table	Elbow strike	P-5	72.77	70
Table Width	Shoulder length hand grip to front	P-50	56.39	55
Table Length	Elbow span length	P-50	79,65	78
		Pipe		
Pipe Length	Height reduced Tiggi elbow	P-50	152.06-72.77= 79.29	85
		Chunk		
Long Chunk	Elbow span length	P-5	56.68	53

5.1 Table design

Table design is carried out by looking at the existing table design, then table size data is obtained from Indonesian anthropometry size data. The design of the 2D welding table can be seen in Figure 6.

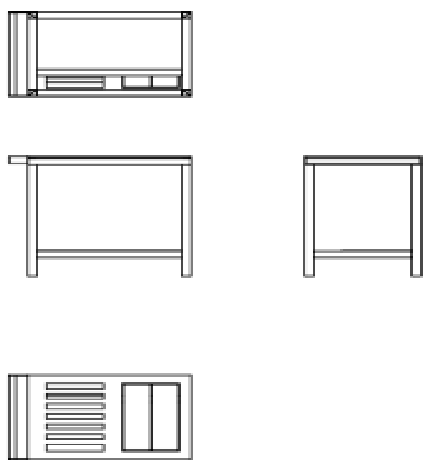


Figure 6. Table 2D drawing design

Anthropometric variable requirements for table size can be seen in Table 8. Table size is referenced from Indonesian anthropometry size data. The design, along with the size, can be seen in Figure 7.

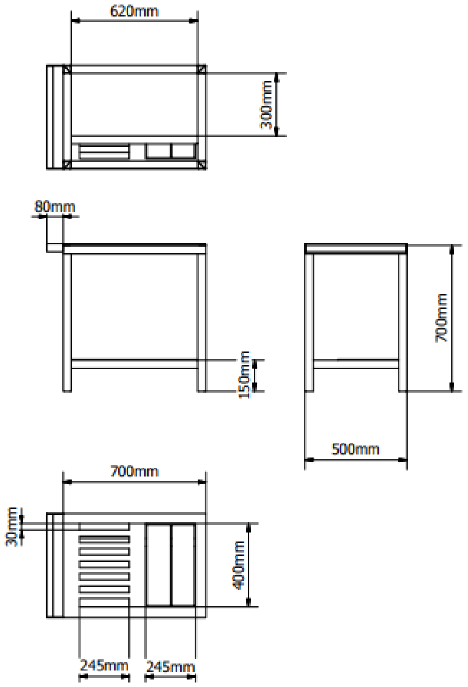


Figure 7. Table 2D drawing design along with size

5.2 Pipe design

Pipe design is carried out by looking at the existing table design, then table size data is obtained from Indonesian anthropometry size data. The 2D pipe design can be seen in Figure 8.

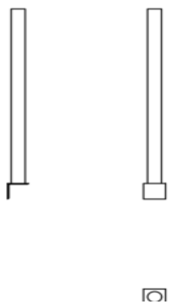


Figure 8. Pipe 2D design drawing

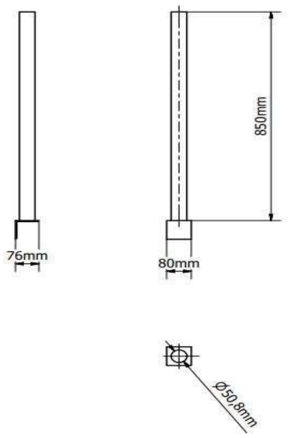


Figure 9. 2D pipe design drawing with size

Anthropometric variable requirements for pipes can be seen in Table 8. The pipe size is referenced from Indonesian anthropometric size data. The design, along with the size, can be seen in Figure 9.

5.3 Clamp design for cylinders

The clamp design for cylinders is inspired by existing table designs and is specifically created to facilitate the welding of tubular or pipe-shaped objects. The clamp design is illustrated in Figure 10, while the dimensional specifications of the clamp for cylinders are detailed in Figure 11.

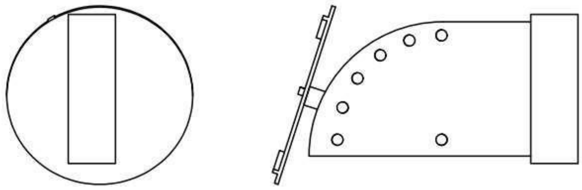


Figure 10. Design drawing 2D clamp for cylinder

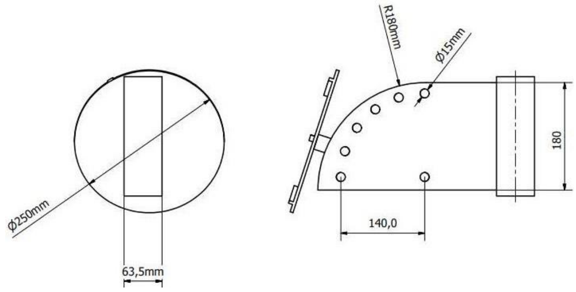


Figure 11. Clamp image design for cylinder with size

5.4 Chunk design

The chunk design is developed based on an analysis of existing chunk designs, incorporating data derived from Indonesian anthropometric measurements. The 2D chunk design can be seen in Figure 12.

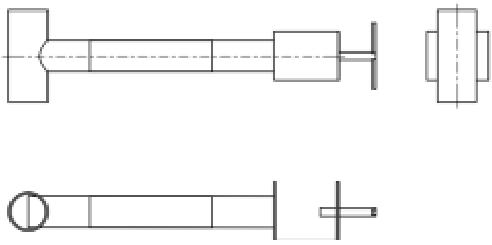


Figure 12. Design 2D chunk images

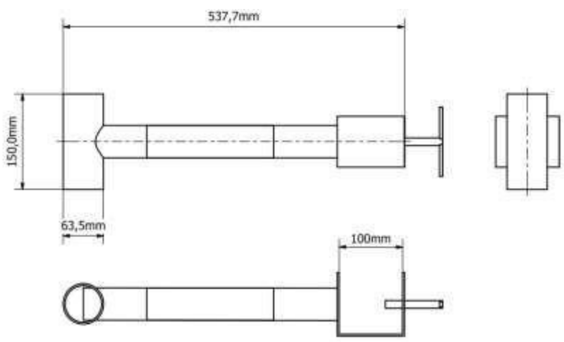


Figure 13. Chunk image design with size

The need for anthropometric variables for chunks can be seen in Table 8. The design, along with the size, can be seen in Figure 13.

5.5 Overall design

At this stage, researchers designed a welding tool with additional chunks and clamps for cylinders from several stages of reverse engineering previously implemented in 3D using AutoCAD software. The overall design of the welding aids can be seen in Figure 14, and a list of the overall design of the welding aids can be seen in Figure 15.

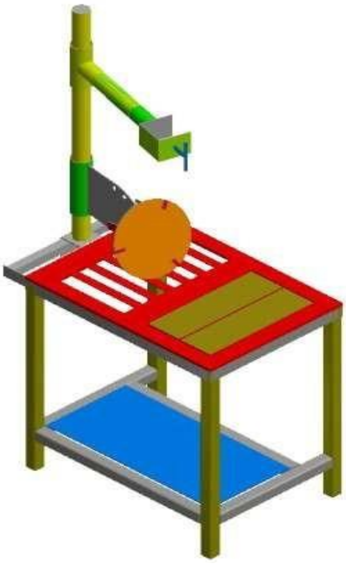
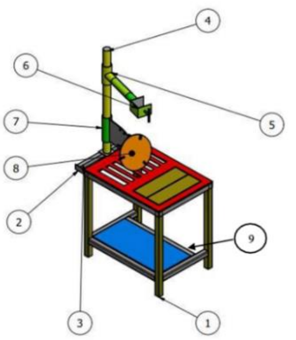


Figure 14. Overall design of welding aids



No Part	Name of Part	Qty
1	Table Frame	1
2	Table Top	1
3	Support Rail	2
4	Retaining Pipe	1
5	Pipe Support	1
6	Plate Handle	1
7	Pipe Support	1
8	Tube Handle	1
9	Equipment Storage	1

Figure 15. Part list

5.6 Product manufacturing stage/prototype

At this stage, a welding aid is made based on a design that has been designed in 2D or 3D. The results of making products/prototypes can be seen in Figure 16.

Based on the results of the product development process, testing is conducted on the designed products. The results show that the designed product meets the needs identified in previous interviews, including its mobility due to the inclusion of wheels and its ability to grip objects in the form of plates securely. This design will make welding tasks easier for workers. It also shows that the tool has been able to grip objects in the form of cylinders to be welded, this has also answered the problem of previous products that were not able to accommodate this need.

Figure 16. Product prototype

6. CONCLUSION

The conclusions that can be drawn from this study based on data collection, design, analysis of design results and based on the objectives of the research, it can be concluded that the design that has been designed can meet user requests and can work well when in the production of tools in the form of prototypes and can function properly. With the reverse engineering method, design is obtained through the stages of disassembly, assembly, benchmarking, and redesign.

Future research should focus on the development of adaptive jigs for various welding techniques and evaluate their performance on a larger scale, incorporating a more diverse sample that includes operators with varying skill levels. The integration of sensor technology and artificial intelligence (AI) could enhance real-time monitoring of jig performance, providing actionable insights for design optimization. Additionally, exploring the use of the jig in welding training programs and conducting a cost-benefit analysis of its implementation within manufacturing industries would offer valuable perspectives. Testing the jig with a range of materials and welding conditions, including extreme temperatures and humidity, would further validate its versatility. The incorporation of advanced ergonomic methods, such as virtual reality (VR) or augmented reality (AR), for digital prototyping and design testing could improve design accuracy prior to physical production. Furthermore, integrating adaptive jigs into Industry 4.0 automation systems has the potential to significantly enhance efficiency, precision, and flexibility in welding processes. Finally, investigating the long-term health impacts on workers-particularly in relation to posture-related injuries-will be crucial in ensuring that the jig design effectively meets ergonomic objectives and supports worker well-being.

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