LOGIC
Journal of Engineering Design and Technology
Vol.22 No.3 Nobember 2022; p. 214 - 224

p-ISSN : 1412-114X
e-ISSN : 2580-5649
http://ojs2.pnb.ac.id/index.php/LOGIC

TENSILE STRENGTH ANALYSIS OF AISI 1045 STEEL RESULTS OF SMAW WELDING USING VARIATIONS OF PREHEAT AND COOLING MEDIA

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Abstract. In the welding process, there are many factors that need to be considered, including heat input, cooling rate, the material being welded, and the use of added materials, if these factors are not considered, they can cause cracks in the American Iron & Steel Institute (AISI) 1045 material. to determine the effect of preheat variations on tensile strength, the effect of cooling media on tensile strength, and to determine the interaction of preheat variations and cooling media on tensile strength. This research method used experimentally by varying the preheat temperature 250ºC, 325ºC, 400ºC, and the cooling medium was lime, sand, and normal air, then tensile test was carried out. The results showed that the cooling medium affected the tensile strength with the highest tensile strength of 64.35 kg/mm^2 on the sand cooling medium, while the preheat variation had no effect on the tensile strength as shown by a graph close to the horizontal straight at the tensile strength ranging from 60 kg/mm^2, interaction between preheat and cooling medium has no effect on tensile strength. This is indicated by the tensile strength values that are almost close to each preheat point, namely at a temperature of 250ºC between 53-67 kg/mm^2, at 325ºC between 56-60 kg/mm^2, and a temperature of 400ºC between 51-64 kg/mm^2. In this study it can be concluded that a good cooling medium uses sand media with a preheat temperature of 250ºC.

Keywords : Tensile Strength, Cooling Media, Welding, Preheat, SMAW.

1. INTRODUCTION

Welding is widely used commercially for joining of metals and alloys at economical rates in various industries. [1]. In manufacturing, welding is an important process, because it is a part of component maintenance and repair activities. Despite, certain challenges associated with high hardness of heat affected zone and cold cracking susceptibility of joints, are the main barriers for this process to be implemented successfully within high integrity structure. [2]. One of the important indicators of metal welding is the strength of the welded joint. [3]. If the welded connection is not strong then there is a risk of structural failure. In the welding process, many factors must be considered, including the incoming heat, cooling rate, the material to be welded, and the use of additional materials. Therefore, welding must also pay attention to the mechanical properties and characteristics of the material being welded, such as whether a material requires heat treatment or not before being welded. [4]. Where the heat treatment will affect the cooling rate of the welded product, which then changes the material properties due to heat treatment and cooling rate. [5].

In an electric arc welding process, the heat distribution through the material at the beginning of the welding it is not homogeneous. This condition is known as a transient state. In theory, after a period of time and a certain distance it becomes uniform, meaning that the quasi-stationary state has been reached. The heat flow during the welding process has an important hole about phases transformations and consequentially about resulting microstructure and materials mechanical properties. [6, 7, 8]. Preheat or preheating [9] is heat given to the parent metal at a certain temperature which is done to slow down the cooling rate so as to produce a metal structure that is more ductile and resistant to cracking. [10]. Research conducted by [11] and [12] early application of heat can increase the value of its tensile strength because the material will become more ductile. Moreover, preheating aims the reduction of the cooling rates and martensitic microstructure within the weld seam. [13, 14].

The importance of AISI 1045 Steel as engineering materials is reflected by the fact that out of the vast majority of engineering grade ferrous alloys available and used in the market today. AISI 1045 Steel is more resistive to cutting, welding, and forming as compared to low carbon steels. Improved tribological and mechanical properties [15] consisting of impact resistance, stiffness, abrasion, and strength are the main reasons for the increased attention of this steel in various industries. In the present scenario for the consolidation of important aspects of various heat treatments and effects on mechanical properties of this steel, a review of different research papers has been attempted. [16]. This study aims to determine the effect of variations in preheat and cooling media on the tensile strength of SMAW welding results. So that in its application it is expected to increase the strength of welded joints in a manufacturing process.

2. METHODS

2.1 Research Concept Framework

This research is included in experimental research because it is to find out the cause and effect relationship caused by the influence on the research process carried out. The independent variables in this study are variation of preheat (250°C, 325°C, and 400°C) and cooling medium (lime, sand, and normal air). The controlled variables in this study are the type of material and flow control. The dependent variable in this study is tensile strength.

Research methods at least describe the approaches used in research, population and research samples, explain the operational definition of variables along with data measurement tools or how to collect data, and data analysis methods. If the data measurement tool uses a questionnaire, it is necessary to include the results of the validity and reliability of the research instrument.

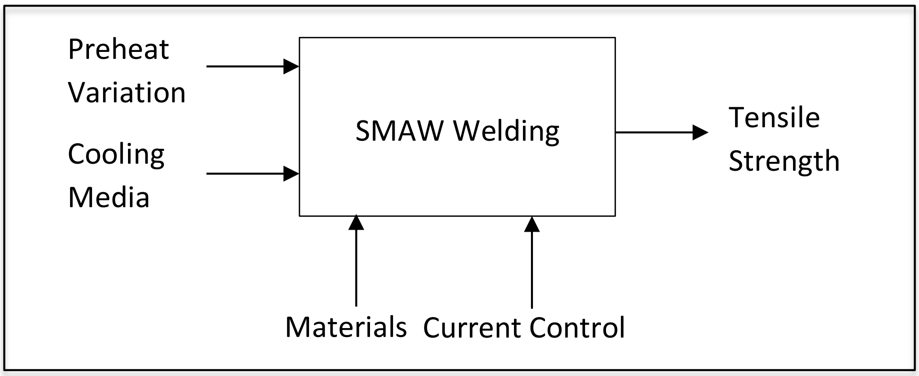

Figure 1. Research Concept Framework

2.2 Tools and Materials

Some of the tools and materials used in this research are:

1. SMAW and OAW welding machine
2. Electrode E7016
3. Welding glasses and hand grinder
4. Pliers, slag hammer, and steel brush
5. Thermocouple and vernier caliper
6. Drilling machine and tensile testing machine

2.3 Research Flowchart

The steps in conducting research follow the sequence of work as follows:

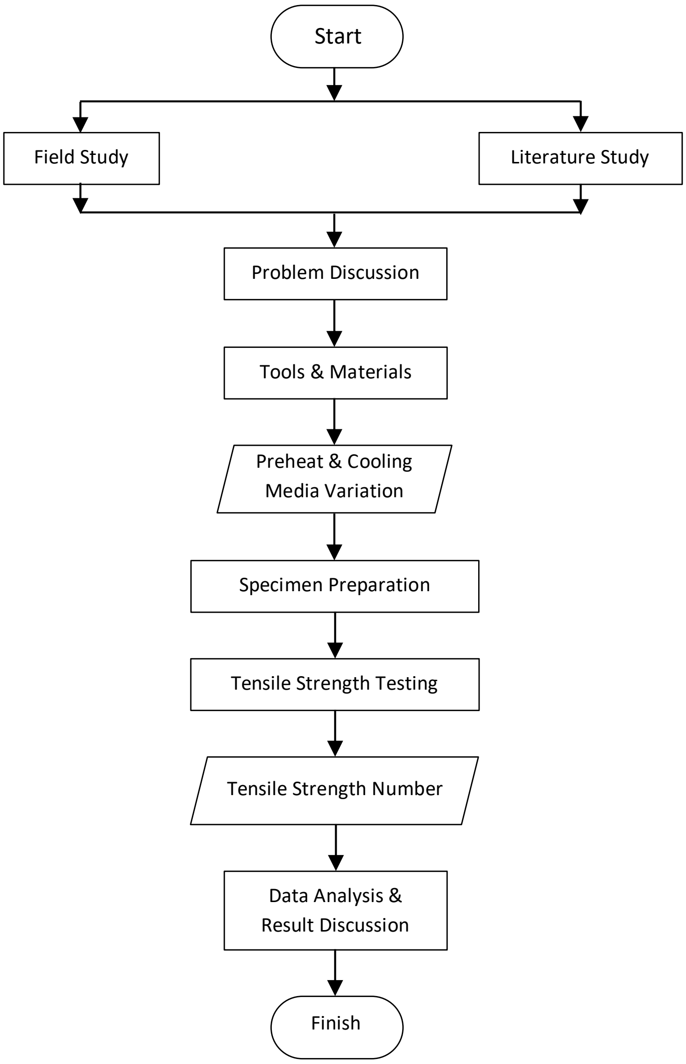

Figure 2. Research Flowchart

Research steps:
1. Learn the background of the problem and the concept of data collection.
2. Direct observation of the object of research and literature study is a literature study of books, journals and previous research.
3. Identify problems to find solutions to problems based on problem identification.
4. Prepare all equipment and materials that will be used as research variables.
5. Preheating is carried out before welding begins using preheat temperatures of 250°C, 325°C, and 400°C.
6. The media used to cool the material after preheating and welding SMAW with lime, sand, and normal air as cooling media.
7. Making tensile test specimens in accordance with British standards.
8. Tests to determine the tensile strength of SMAW welding results with variations in preheat and cooling media.
9. Analyze the data obtained from the tensile test and find out the influence of each variable. The data processing method used in this study is factorial ANOVA which is to determine the effect of variations in preheat and cooling media on the tensile strength of SMAW welding results.

3. RESULTS AND DISCUSSION

3.1 Tensile Strength Results

In this study, the tensile strength resulted in 4 discussions, namely tensile strength, yield value, total elongation, and plastic elongation, where all these parameters refer to previous research. [17]. The data obtained from the test is then calculated and processed, then displayed in the form of tables and graphs below:

Table 1. Tensile Strength Data

Preheat Temp.	Cooling Media		
	Lime	**Sand**	**Normal Air**
250^{0}C	60.92	68.28	52.15
	47.19	67.09	60.53
	51.92	67.85	55.77
Average	**53.34 kg/mm^2**	**67.74 kg/mm^2**	**56.15 kg/mm^2**
325^{0}C	59.56	58.16	45.92
	53.01	62.82	69.29
	56.68	60.31	58.60
Average	**56.41 kg/mm^2**	**60.43 kg/mm^2**	**57.93 kg/mm^2**
400^{0}C	51.18	65.95	53.48
	52	65.70	50.98
	57.01	63.03	51.46
Average	**53.39 kg/mm^2**	**64.89 kg/mm^2**	**51.97 kg/mm^2**

Table 2. Annova and Summary Model of Tensile Strength

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	700.23	87.53	3.37	0.015
Linear	4	569.01	142.25	5.47	0.005
Preheat	2	25.00	12.5	0.48	0.626
Cooling Media	2	544.01	272.00	10.46	0.001
2-Way Interactions	4	131.22	32.81	1.26	0.321
Preheat*Cooling Media	4	131.22	32.81	1.26	0.321
Error	18	468.20	26.01		
Total	26	1168.44			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
5.10013	59.93%	42.12%	9.84%

The ANOVA results show that the preheat variation has no significant effect where P-value > then the null hypothesis (H_0) is accepted, while the cooling medium shows the results where the cooling medium has a significant effect on the response P-value < then the null hypothesis (H_0) is rejected and the interaction of the two independent variables on the dependent variable (response) has no significant effect, then the null hypothesis (H_0) is accepted. The value of the determinant coefficient (R^2) is 59.93% where the two independent variables have a significant effect on the response, while 40.07% is influenced by errors and other factors that influence during the research.

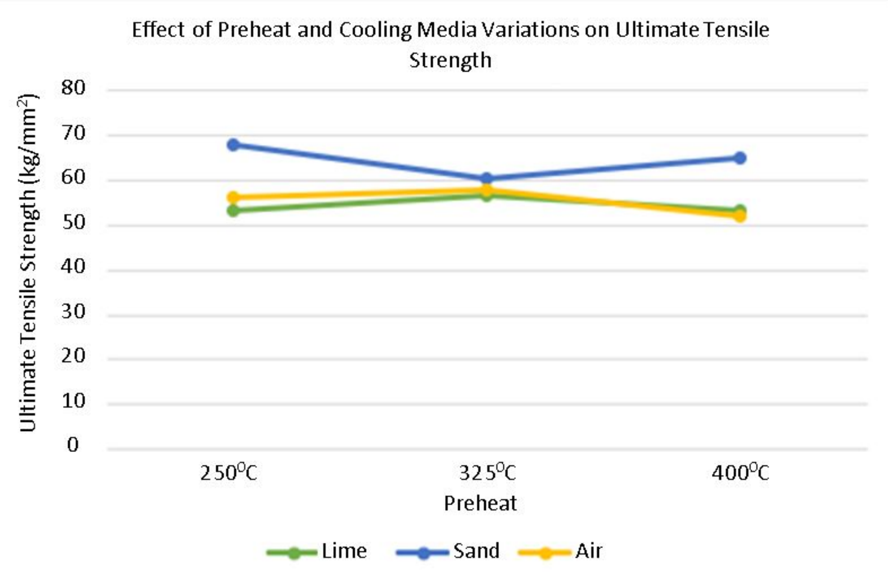

Figure 3. Ultimate Tensile Strength

The results on the graph show that the highest tensile strength value is produced at a temperature of 250°C and the cooling medium is sand at 67.74 kg/mm^2 while the lowest tensile strength value is 51.97 kg/mm^2 at a temperature of 400°C with normal air cooling. The results of the increase can be seen because the material is said to be brittle because of the fast cooling rate and it is possible to transform into mertensite so that it increases the tensile strength value, while the result is a decrease in tensile strength because the cooling rate of the material is slow so that it produces a ductile structure, because if the stress value is increases, the strain value will tend to decrease more. In the other words, the temperature distribution was affected by preheat temperatures, increasing the preheat temperatures leads to decrease the cooling rates. [18].

3.2 Yield Strength Results

The test results data for the yield strength values are shown in the following table.

Table 3. Yield Strength Data

Preheat Temp.	Cooling Media		
	Lime	**Sand**	**Normal Air**
250°C	60.28	66.52	50.70
	44.64	61.99	53.34
	48.71	62.85	50.09
Average	**51.21 kg/mm^2**	**63.79 kg/mm^2**	**51.38 kg/mm^2**
325°C	58.18	54.92	36.05
	51.70	57.48	67.28
	52.89	55.28	51.19
Average	**54.25 kg/mm^2**	**55.89 kg/mm^2**	**51.51 kg/mm^2**
400°C	43.79	65.29	53.24
	48.09	61.52	46.54
	45.39	57.33	47.15
Average	**45.76 kg/mm^2**	**1.38 kg/mm^2**	**48.98 kg/mm^2**

Table 4. Annova and Summary Model of Yield Strength

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	803.1	100.38	2.46	0.053
Linear	4	634.15	158.54	3.89	0.019
Preheat	2	52.78	26.39	0.65	0.535
Cooling Media	2	581.37	290.69	7.13	0.005
2-Way Interactions	4	168.86	42.21	1.04	0.416
Preheat*Cooling Media	4	168.86	42.21	1.04	0.416
Error	18	733.50	40.75		
Total	26	1536.51			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
6.38359	52.26%	31.04%	0.00%

The ANOVA results show that the preheat variation has no significant effect where P-value > then the null hypothesis (H_0) is accepted, while the cooling medium shows the results where the cooling medium has a significant effect on the response P-value < then the null hypothesis (H_0) is rejected and the interaction of the two independent variables on the dependent variable (response) has no significant effect, so the hypothesis is null (H_0). The value of the determinant coefficient (R^2) in the study was 52.26% where the two independent variables had a significant effect on the response, while 47.74% was influenced by errors and other factors that influenced the research.

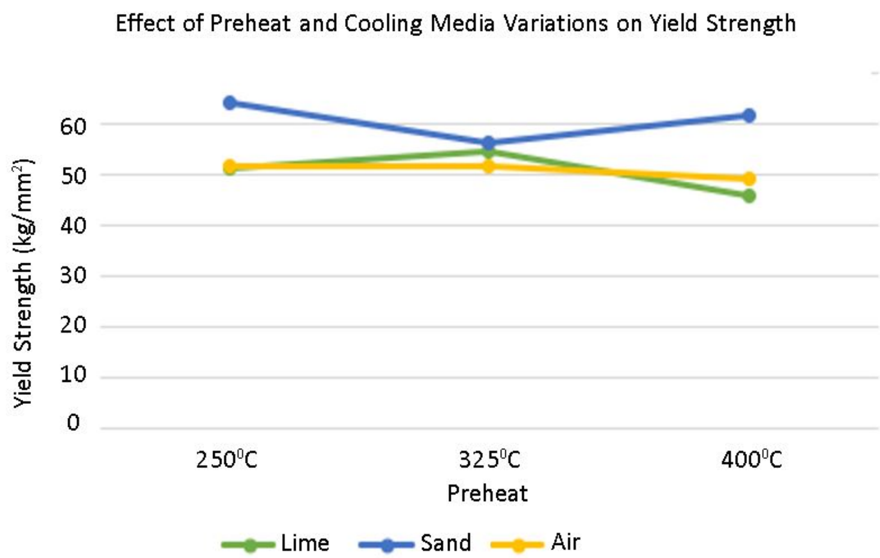

Figure 4. Yield Strength

Figure 4 shows the results where the yield value generated from the scrambled test is the highest yield value of 63.7924 kg/mm² produced at a preheat temperature of 250°C with sand cooling media while the lowest yield value of 45.7589 kg/mm² is produced at a preheat temperature 400°C with lime cooling medium. Yield value or also known as yield strength is the limit or point where the material continues to deform without any additional load, yielding symptoms that occur in a material are generally shown in ductile materials, then the yield value for ductile materials is the elasticity limit of the material before turn plastic. [19]

3.3 Total Elongation Results

The test results data for the total elongation value are as follows.

Table 5. Total Elongation Data

Preheat Temp.	Cooling Media		
	Lime	**Sand**	**Normal Air**
250°C	20	14	12
	16	16	8
	16	14	10
Average	**17.33 %**	**14.66 %**	**10 %**
325°C	14	14	17
	14	18	22
	14	14	20
Average	**14 %**	**15.33 %**	**21.66 %**
400°C	10	16	15
	12	10	12
	12	12	12
Average	**12.66 %**	**12.66 %**	**13 %**

Table 6. Annova and Summary Model of Total Elongation

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	220.074	27.5093	8.07	0.000
Linear	4	80.815	20.2037	5.93	0.003
Preheat	2	80.519	40.2593	11.82	0.001
Cooling Media	2	0.296	0.1481	0.04	0.958
2-Way Interactions	4	139.259	34.8148	10.22	0.000
Preheat*Cooling Media	4	139.259	34.8148	10.22	0.000
Error	18	61.333	3.4074		
Total	26	281.407			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.84592	78.20%	68.52%	50.96%

The ANOVA results show that the preheat variation has a significant effect on the dependent variable (response) where P-value < then the null hypothesis (H_0) is rejected, while the cooling medium shows the result where the cooling medium has no significant effect on the response P-value > then the null hypothesis (H_0) is accepted and the interaction of the two independent variables on the dependent variable (response) has a significant effect, then the null hypothesis (H_0) is rejected. The value of the determinant coefficient (R^2) in the study was 78.20% where the two independent variables had a significant influence on the response, while 21.80% was influenced by errors and other factors that influenced the research.

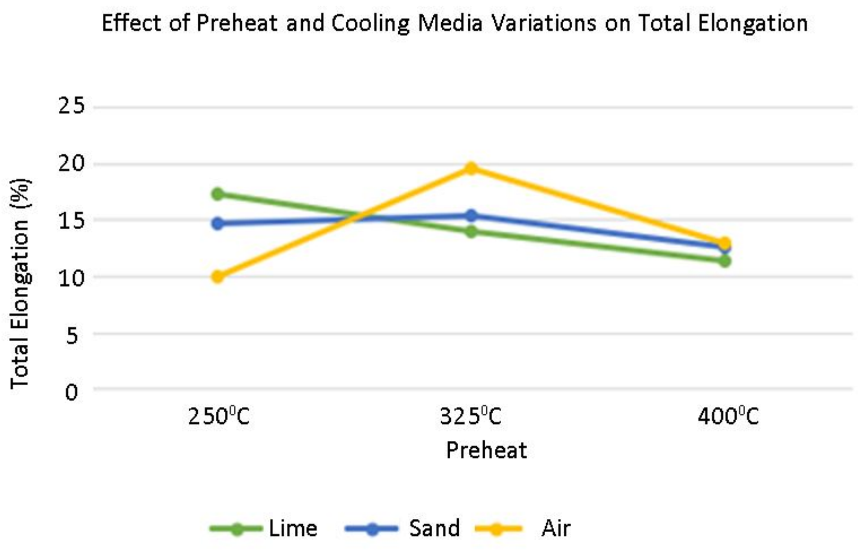

Figure 5. Total Elongation

Figure 5 shows the total elongation results where the interaction temperature of 325°C with normal air cooling produces the highest elongation value of 19.66% while the lowest elongation of 10% is produced at a preheat temperature of 250°C with normal air cooling. An increase in the elongation value is influenced by the high preheat temperature where the higher the preheat temperature the material will be more ductile due to slow cooling and allows for more ferrite transformations while other factors that influence are the density or density of the cooling medium where the density is getting smaller, the cooling rate will be slower [20].

3.4 Plastic Elongation Results

The test results for plastic elongation are as follows.

Table 7. Plastic Elongation Data

Preheat Temp.	Cooling Media		
	Lime	**Sand**	**Normal Air**
250⁰C	0.06	0.06	0.06
	0.06	0.06	0.06
	0.06	0.06	0.06
Average	**0.06 mm**	**0.06 mm**	**0.06 mm**
325⁰C	0.04	0.02	0.04
	0.08	0.02	0.1
	0.06	0.02	0.08
Average	**0.06 mm**	**0.02 mm**	**0.07 mm**
400⁰C	0.04	0.04	0.04
	0.04	0.04	0.02
	0.04	0.04	0.04
Average	**0.04 mm**	**0.04 mm**	**0.03 mm**

Table 8. Annova and Summary Model of Plastic Elongation

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	0.006963	0.000870	5.34	0.002
Linear	4	0.003526	0.000881	5.41	0.005
Preheat	2	0.002252	0.001126	6.91	0.006
Cooling Media	2	0.001274	0.000637	3.91	0.039
2-Way Interactions	4	0.003437	0.000859	5.27	0.005
Preheat*Cooling Media	4	0.003437	0.000859	5.27	0.005
Error	18	0.002933	0.000163		
Total	26	0.009896			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0127657	70.36%	57.19%	33.31%

The ANOVA results show that the preheat variation has a significant effect on the dependent variable (response) where P-value < then the null hypothesis (H_0) is rejected, while the cooling medium shows the results where the cooling medium has a significant effect on the response P-value < then the null hypothesis (H_0) is rejected and the interaction of the two independent variables on the dependent variable (response) has a significant effect, so the null hypothesis (H_0) is rejected. The value of the determinant coefficient (R^2) in the study was 70.36% where the two independent variables had a significant effect on the response, while 29.64% was influenced by errors and other factors that influenced the research.

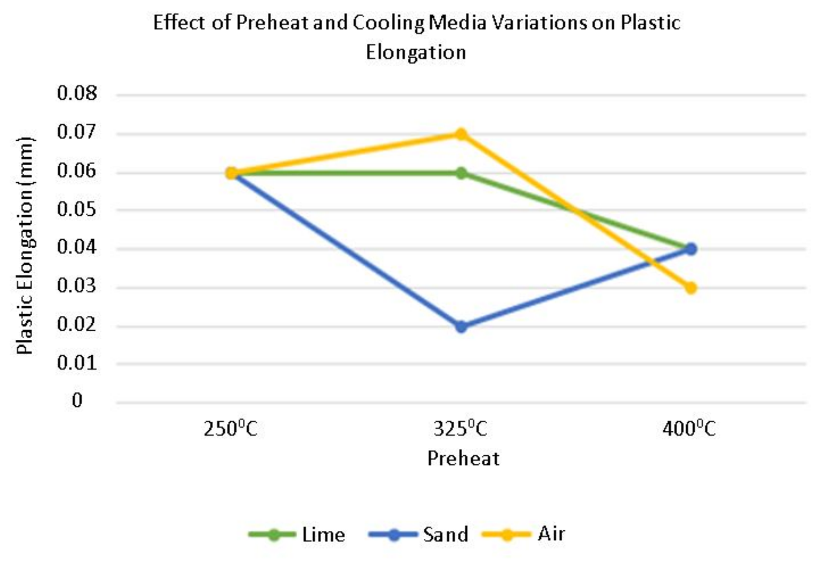

Figure 6. Plastic Elongation

Figure 6 shows a graph where the interaction at a preheat temperature of 325°C with normal air cooling produces a plastic elongation value of 0.07 mm while the lowest plastic elongation of 0.02 mm is produced at a preheat temperature of 325°C with lime cooling media. The increase in the plastic elongation value is influenced by the nature of the more ductile material due to the slow cooling rate and it is possible to transform to more ferrite so that the material is more ductile, so the plastic elongation value will be higher.

4. CONCLUSION

Based on the research that has been done, it can be concluded several things below:

a. The results of the study on the effect of the interaction between variations of preheat and cooling media on tensile strength showed that at a preheat temperature of 250^{0}C with the interaction of the sand cooling medium, the highest tensile strength was 67.74 kg/mm^2, while the lowest tensile strength was at the interaction of preheat temperature of 400^{0}C with air cooling. normal value is 51.97 kg/mm^2, where it is possible that there is a change in the brittle nature with more martensite transformation and a slow cooling rate which is influenced by variations in preheat and cooling media so that the material is ductile so that if the stress value increases, the strain value will tend to decrease.

b. The results of the discussion in the study above show that the interaction between preheat and cooling media variations on the yield value shows the highest yield value of 63.7924 kg/mm^2 using a temperature of 250^{0}C with sand cooling media while the lowest yield value is 45.7589 kg/mm^2 using a temperature 400^{0}C preheat and lime cooling medium.

c. In the above study, the results of the interaction between variations of preheat and cooling media on total elongation showed the highest elongation value of 19.66% at a preheat temperature of 325^{0}C with normal air cooling, while the lowest elongation value was 10% at a preheat interaction of 250^{0}C with normal air cooling.

d. Based on the results of the research above, the results of the interaction of variations in preheat and cooling media on plastic elongation show that the highest plastic elongation is at a preheat temperature of 325^{0}C with normal air cooling with a plastic elongation value of 0.07 mm while the lowest elongation value is at a preheat temperature of 325^{0}C with cooling media. lime with a plastic elongation value of 0.02 mm, where an increase in elongation value or a decrease can also be influenced by several factors, including preheat temperature, the effect of the density of each cooling medium and the transformation of microstructure.

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