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ANALYSIS OF PROCESS TIME AND COPPER SLAG REQUIREMENTS IN THE SHIP HULL BLASTING PROCESS

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ABSTRACT

The blasting process in the shipping industry aims to clean the surface of the plate from dirt, rust, and mill scale, and provide surface roughness so that the paint layer can adhere well. In the blasting process, abrasive materials are often used once or twice, but in field practice, reused copper slag has been used as an abrasive material. This study aims to analyze the weight of abrasive material requirements and process time during the blasting process using the Analysis of Variance (ANOVA) method with variations in new copper slag use, reused copper slag 1 and 2 as abrasive materials reaching the standard cleanliness level of SA 2.5 and the surface roughness level according to the International Maritime Organization (IMO) Performance Standard for Protective Coatings (PSPC) 30 – 75 mikron and the International Organization for Standardization (ISO) 8501-1. The results of this study indicate that fresh copper slag and reused copper slag-1 exhibit lower effectiveness in the blasting process; both types of copper slag require a longer time to reach the SA 2.5 cleanliness standard, resulting in increased abrasive material requirements. On the other hand, reused copper slag-2 exhibits better performance with shorter blasting time and minimal abrasive material requirements in accordance with the ISO 8501-1 SA 2.5 cleanliness level.

Keywords: ANOVA, blasting, copper slag, ISO 8501-1, process time

Introduction

The shipbuilding industry encompasses two main aspects: new shipbuilding and repairs, which require the removal of surface dirt and rust from steel plates to allow for subsequent painting. Therefore, blasting is necessary. The blasting method produces optimal surface cleanliness with a relatively high productivity rate of approximately 7 to 8 square meters per hour. This blasting technique is applied to remove rust caused by oxidation, caused by the interaction between seawater and air, remove mill scale from new plates, and create surface roughness to improve adhesion between the material and the coating during painting. The advantages of the blasting process lie in its speed and flexibility in adapting to the complex curves of the workpiece during the forming process. Factors that influence the results of blasting include the human element, the air pressure used for firing, the abrasive material used, the firing time, and the firing distance.

Blasting is divided into two categories, namely dry blasting and wet blasting. Dry blasting is generally applied to metal materials that are not at risk of burning, for example, for corrosion removal or paint removal. On the other hand, wet blasting is applied to metals that are at risk of burning or that are in areas with the potential for fire, for example, in fuel tanks, offshore oil refineries, and fuel stations. In the wet blasting method, the sand used for spraying is mixed with special chemicals that have anti-rust properties, aiming to reduce sparks when the sand comes into contact with the metal during the blasting process [1]. The success of the coating process is highly dependent on the surface preparation stage, which influences the bond strength of the material [2]. One common surface preparation method used in industry is blasting. This method involves cleaning a surface by spraying an abrasive material onto the surface at high pressure, creating friction or impact. The surface is then cleaned and roughened. Selecting and using the right abrasive material will improve paint adhesion [3,4]. Paint functions as a coating with three main functions: decoration, increasing adhesion, and protecting the object's surface from corrosive environments. The basic components of paint are four elements: binder, pigment, solvent or thinner, and additives [5]. Based on [6] Indonesian Classification Bureau (BKI) regulations in vol G "Guidance for Coating performance Standards" section 3 sub-chapter coating inspection agreement which refers that the cleanliness standards and surface roughness level for ship hull plates follow the IMO PSPC (Performance Standard for Protective Coatings) ANNEX 1 standard in paragraph 2 that the surface cleanliness level must reach the ISO 8501-1 SA 2.5 standard and the surface roughness level achieved is between 30 μm to 75 μm [7].

In general, blasting uses silica sand as an abrasive material. However, over time, the use of silica sand has shifted to other abrasive materials. This is because silica sand contains heavy metal elements exceeding the quality standards based on PP No. 101 of 2014, so it is classified as a hazardous and toxic material (B3). Fly ash from silica sand is categorized as toxic and hazardous waste by the Environmental Impact Management Agency (Bapedal) [8]. Blasting can be a dangerous process because it can produce airborne particles that are harmful if inhaled, and can also produce significant amounts of dust and debris. Proper safety precautions, including the use of protective clothing, respiratory protection, and control measures, are essential when performing blasting operations [9].

Blasting processes carried out outdoors will produce dust pollution in the atmosphere, which is very risky for the ecosystem, especially related to the health of workers in the surrounding area. The dust particles created will be dispersed in the air according to the direction of the wind until they reach areas outside the port and shipyard. The most dangerous particles, with a size of less than 2.5 μm, can trigger respiratory tract diseases such as coughs, colds, and sore throats, as well as disrupt lung function, which can increase the risk of heart disease. Based on Government Regulation of the Republic of Indonesia No. 22 of 2021 concerning the Implementation of Environmental Protection and Management and Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. 14 of 2020 concerning the Air Pollution Standard Index for Ambient Air Quality Standard Values that have been established, the port and shipyard industry must pay attention to the extent of the spread of dust particles in the air due to sandblasting activities which have the potential to harm the environment, especially for workers in the port and shipyard areas and the surrounding environment [10]. Continuous exposure to fly ash from silica sand can cause silicosis in human lungs [11]. In 1983, Shaman estimated that over one million US workers were at risk of developing silicosis and that over 100,000 of these workers were sandblasters. Because of its potential health hazards, NIOSH has recommended that silica sand (or substances containing more than 1% crystalline silica) be banned from blasting abrasives and that less hazardous materials be used as substitutes. As part of this recommendation, NIOSH identified metallurgical slag abrasives, such as copper slag, as acceptable substitutes for silica sand. Although NIOSH reports that metallurgical slag is used in only 3.1 percent of facilities performing abrasive blasting, its increasing use has been recognized in other literature [12]. Therefore, alternatives to silica sand as an abrasive are needed, one of which is copper slag. Much research has been conducted to determine the properties of copper slag in blasting operations. This material offers fast cleaning applications and saves material because the product can be reused several times. Copper slag is one of the most sought-after blasting materials in Europe and was first introduced in 1960. Since then, copper slag has been widely used to remove rust, old paint layers, and contaminated layers on metal, stone, concrete, and brick surfaces, especially in the metal, automotive, shipbuilding, and petrochemical industries.

Copper slag has been used in the shipping industry as an abrasive material in the blasting process on the surface of ship hull material. Its physical and chemical properties recommend this material as one of the most effective explosives, which can be used on almost all types of surfaces, both indoors and outdoors. Copper slag is an ecological and non-toxic product (free silica content < 0.1%) [13] which sets the technical specifications for copper slag as a safe and effective non-metallic abrasive medium and [14] which ensures that copper slag has been tested and passed international standard test methods regarding quality, chemical composition, hardness, and safety of its use in the blasting process. Copper slag is a popular choice for abrasive blasting due to its fast-cutting speed and low dust content. When compared to coal slag, copper slag has a higher density (around 20%) and can be recycled many times.

This makes copper slag a more cost-effective option, as it results in faster blasting and reduced product consumption [15]. To determine the efficiency of copper slag as a blasting material, which includes the area cleaned per hour, and the consumption of abrasive to clean the reference surface [16,17]. It stated that the use of abrasive materials is only for one-time use, which means that the residue from the first use will be discarded [18]. This used abrasive material has several options for reuse, including being reused as abrasive material for blasting processes, building materials, road construction materials, and being processed into non-hazardous waste. University of New Orleans, Department of Civil and Environmental Engineering. It is considered that copper slag is a very efficient blasting material, with excellent properties for cleaning and blasting various types of surfaces. Because it is an ecological product, copper slag can be successfully used in open-air blasting, with minimal impact on the environment. The possibility of material reuse allows material savings.

Methodology

a. Flow Chart

This study aims to analyze the blasting process time and weight of copper slag requirements on ship hull plates with variations of new copper slag and reused copper slag 1 and 2. This methodology is systematically illustrated in a flow chart (Figure 1) and begins with basic steps before proceeding to the preparation, testing, and analysis phases.

In the literature study stage, a theoretical basis or literature review is carried out by searching for references or sources of information to help complete this research. The literature review was taken from books, the internet, journals, and from the supervising lecturers. A survey was conducted regarding the parameters used as research objects. Such as a survey of the blasting process location, abrasive materials, etc. In the problem identification stage, many things need to be considered in order to achieve useful and refined research results [19]. Then, the preparation of test specimens was carried out, especially carbon steel samples with dimensions of 50 cm long x 50 cm wide and 8 mm thick. Next, the blasting process was carried out using new copper slag material and reused copper slag 1 and 2 to clean and prepare the specimens [20].

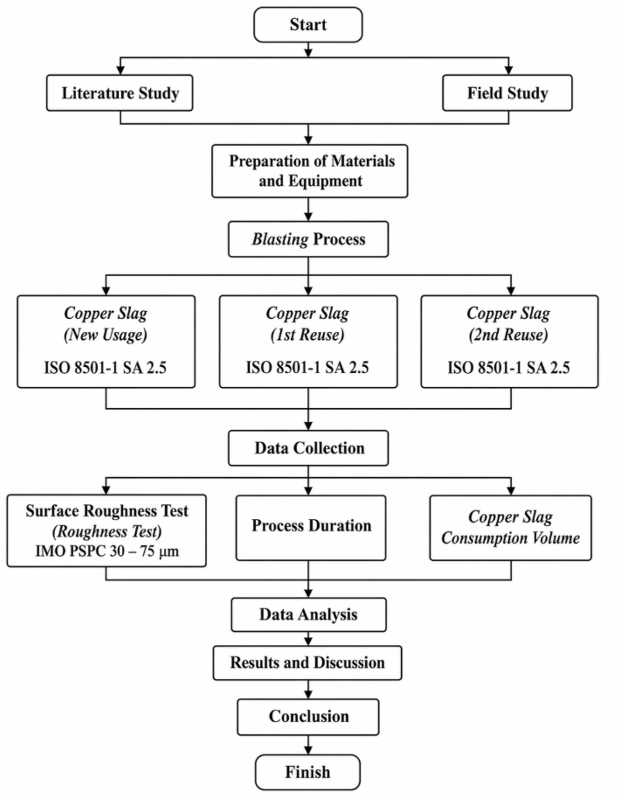

Figure 1. Flowchart

Before the blasting process was carried out, the area humidity was calculated using an Elcometer for 2 minutes. Next, the sand tank was filled with copper slag. The abrasive material that enters must be a maximum of 80% of the sandbox volume so that the abrasive material does not spill during the blasting process, before the abrasive material is put into the sandbox, the initial weight (input) is weighed and after the blasting process, the weight (output) of the remaining abrasive material in the sandpot is weighed again to determine the weight needed for the blasting process. The blasting process is carried out to calculate the blasting process time using a stopwatch to determine the time needed to achieve the cleanliness level according to the ISO 8501-1 SA 2.5 standard. Repeat the blasting process on other specimens with reused copper slag 1 and 2. Visual inspection is carried out to comply with the ISO 8501-1 SA 2.5

standard. After the data on the process time and the weight of the requirements are obtained, the results of the data are analyzed using Analysis of Variance (ANOVA) to determine the significance of copper slag variations on the blasting process time and the weight of the copper slag requirements.

b. Test Materials and Equipment

1) Test Materials
    - ASTM A36 Carbon Steel
    - Abrasive materials, new copper slag, and reused copper slag 1 and 2
2) Test Equipment
    - Compressor
    - Hose
    - Nozzle
    - Sandpot
    - Elcometer 319
    - Digital Scale
    - Stopwatch

c. Research Procedure

1) The steel material that is the main material of the research object is ASTM A36 steel with dimensions of 500 mm long x 500 mm wide x 8 mm thick. The abrasive material used is copper slag. The variation of this research lies in the abrasive material, with a comparison between the new abrasive material, reused abrasive material 1, and reused abrasive material 2. The material shown in Figure 2 illustrates one of the specimens that will be used during the blasting process.

Figure 2. One example of a specimen before the blasting process

2) Before the blasting process is carried out, the temperature of wet and dry air is measured using an electrometer for 2 minutes. The difference between the wet and dry air temperatures is entered into the Dew Point (DP) and Relative Humidity (RH) to obtain the Dew Point (DP) and Relative Humidity (RH) values. Environmental conditions are ensured so that the relative humidity is below 85% and the substrate temperature is 3°C greater than the dew point. Figure 3 presents a visual depiction of the process of measuring the humidity of the area temperature.

Figure 3. The process of measuring the temperature and humidity of the area

3) The sandbox is filled with new copper slag abrasive material. The abrasive material entering here must be a maximum capacity of 80% of the sandbox volume to prevent the abrasive material from spilling during the process. Before the abrasive material is put into the sandbox, the initial weight (input) is weighed, and after the blasting process, the weight (output) of the remaining abrasive material in the sandpot is weighed again to determine the weight required for the blasting process. Figure 4 shows the process of putting copper slag into the sandpot.

Figure 4. Put copper slag into the sandpot

4) The blasting process was carried out, and the process time was calculated using a stopwatch to determine the time required to achieve surface cleanliness of SA 2.5 according to the ISO 8501-1 standard. The used material from the first blasting was collected in a container and sieved, but this shipyard had already gone through the process, so that the used abrasive material was ready stock in the workshop. Repeat the blasting process on other specimens with reused abrasive material 1 and continue with reused abrasive material 2. Figure 5 shows a visual of the plate after the blasting process.

Figure 5. One of the specimens after the blasting process

d. Research Work

1) Weighing copper slag requirements

Weighing abrasive material requirements is carried out using a digital scale to obtain accurate consumption data. Before the blasting process begins, the initial weight of the abrasive is measured when the material is loaded into the sandpot and recorded as the input weight. After the blasting process is complete, the remaining abrasive in the sandpot is weighed again using the same digital scale. The difference between the initial and residual weights is then calculated as the abrasive requirement weight during the blasting process (see the weighing process in Figure 6.

Figure 6. Process of weighing the weight of copper slag requirements

2) Calculating the Blasting Process Time

At this stage, data is collected to measure the blasting process time until it reaches a cleanliness level of SA 2.5 through direct observation using a stopwatch on a mobile phone. Before the measurement begins, the operating parameters are ensured to be in accordance with standards, including working pressure, abrasive type, and initial surface condition. The stopwatch is reset, and the time is recorded from the time the operator begins blasting. Figure 7 illustrates the process of calculating the time during the blasting process.

Figure 7. Process of taking data on the blasting process time towards SA 2.5

3) Visual inspection of cleanliness level SA 2.5
After the blasting process, a visual inspection of the blasting results is performed by comparing them to the ISO standard: 8501-1 1988 "Preparation of Steel Substrates Before Application of Paints and Related Products – Visual Assessment of Surface Cleanliness. The desired cleanliness level, SA 2.5 (very thorough blast cleaning), is shown in Figure 8.

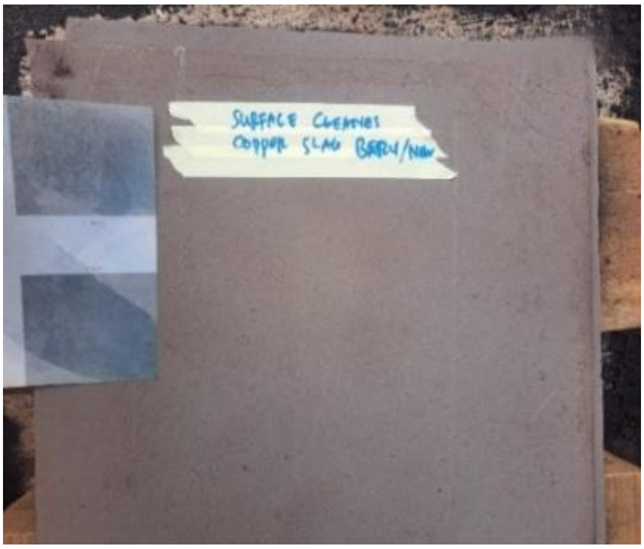

Figure 8. Cleanliness level inspection process according to ISO 8501-1 SA 2.5 standard

4) Data Collection
At this stage, data was collected directly from the blasting process results, including the time required to reach the SA 2.5 cleanliness standard using a stopwatch and the weight of copper slag required in the blasting process to reach the SA 2.5 cleanliness standard, with variations of new copper slag, reused copper slag -1, and 2.

5) Data Analysis Using ANOVA
This study used Analysis of Variance (ANOVA). This technique is used to determine whether there are significant differences between the means of three or more groups based on one independent variable. Before conducting both studies, the data underwent a normality test. Data analysis used IBM SPSS 27 statistical software.

Result and Discussion

a. Results of the blasting process time

The recorded time reflects the optimal pressure, abrasive type, and operator technique in achieving that level of cleanliness. Consistent duration indicates the process is operating within stable operating parameters, while too short or too long a time can indicate inappropriate operating conditions [21]. Thus, blasting time serves as an indicator of process performance and compliance with applicable surface cleanliness standards. Using fresh copper slag and reused copper slag 1 and 2 in the blasting process, the surface processing time data is obtained in Table 1.

Table 1. Blasting process time data results

Sample	**Time for Area 0.25 m^2 (min)**	**Time for Area 1 m^2 (min)**
Copper slag new use I	1,18	4,72
Copper slag new use II	1,20	4,80
Copper slag new use III	1,19	4,76
Average	1,19	4,76
Copper slag reuse– 1 I	1,04	4,16
Copper slag reuse– 1 II	1,00	4,00
Copper slag reuse– 1 III	1,01	4,04
Average	1,01	4,07
Copper slag reuse– 2 I	0,42	1,68
Copper slag reuse– 2 II	0,49	1,96
Copper slag reuse– 2 III	0,44	1,76
Average	0,45	1,80

Based on Table 1, specimens with new copper slag variations have an average blasting process time value towards SA 2.5 for an area of 0.25 m^2 of 1.19 min and for an area of 1 m^2 of 4.76 min, specimens with reuse copper slag variations-1 have an average blasting process time value towards SA 2.5 for an area of 0.25 m^2 of 1.01 min and for an area of 1 m^2 of 4.07 min, specimens with reuse copper slag variations-2 have an average blasting process time value towards SA 2.5 for an area of 0.25 m^2 of 0.45 s and for an area of 1 m^2 of 1.80 min.

Table 2. Results of data on the weight of copper slag required

Sample	Weight Required for an Area of 0.25 m^2 (kg)	Weight Required for an Area of 1 m^2 (kg)
Copper slag new use I	4,80	19,20
Copper slag new use II	4,65	18,60
Copper slag new use III	4,50	18,00
Average	4,65	18,60
Copper slag reuse– 1 I	4,30	17,20
Copper slag reuse– 1 II	4,15	16,60
Copper slag reuse– 1 III	4,10	16,40
Average	4,18	16,73
Copper slag reuse– 2 I	3,35	13,40
Copper slag reuse– 2 II	3,45	13,80
Copper slag reuse– 2 III	3,15	13,60
Average	3,31	13,27

b. Weight results of copper slag requirements

The results of the weight of the abrasive material required in the blasting process towards SA 2.5 indicate the level of efficiency of abrasive material use during surface cleaning. The weight of the abrasive material used indicates how effective the particles are in removing rust, mill scale, and old coatings to achieve the ISO 8501-1 visual standard. Low abrasive material consumption can indicate particle effectiveness and stable operating parameters, while high consumption can indicate a heavy initial surface condition, insufficient pressure, or poor surface finish. optimal, or decreased abrasive quality. The data on the weight of requirements obtained is presented in Table 2.

Based on Table 2, specimens with new copper slag variations have an average value of the weight of the blasting process requirements towards SA 2.5 for an area of 0.25 m^2 of 4.65 kg and for an area of 1 m^2 of 18.60 kg, specimens with reused copper slag variations-1 have an average value of the weight of the blasting process requirements towards SA 2.5 for an area of 0.25 m^2 of 4.18 kg and for an area of 1 m^2 of 16.73 kg, while specimens with reused copper slag variations-2 have an average value of the weight of the blasting process requirements towards SA 2.5 for an area of 0.25 m^2 of 3.31 kg and for an area of 1 m^2 of 13.27 kg.

Table 3. Results of the normality test for blasting process time

Test of Normality						
Types of Copper Slag	Kolmogorov-Smirnov			Shapiro-Wilk		
	Stat.	df	Sig.	Stat.	df	Sig.
Copper Slag New Use	0.175	3		1.000	3	1.00
Copper Slag Reuse–1	0.292	3		0.923	3	0.46
Copper Slag Reuse–2	0.276	3		0.944	3	0.53

c. Results of the analysis of the blasting process time

Statistical analysis was performed to determine the significance of the effect of variations in new copper slag and reused copper slag grades 1 and 2 on blasting process time. Normality and homogeneity tests were performed as a preliminary evaluation to select the appropriate statistical method. The results of the normality test are presented in Table 3, while the results of the homogeneity test are shown in Table 4.

When the data met the assumptions of normality and homogeneity, Analysis of Variance (ANOVA) was used to analyze differences between groups. The ANOVA results for the blasting process time data are shown in Table 5. The ANOVA results indicate that copper slag variation has a statistically significant effect on blasting process time.

Table 4. Results of the homogeneity test of the blasting process time

Tests of Homogeneity of Variances				
	Levene Statistic	**df1**	**df2**	**Sig.**
Based on Mean	2.681	2	6	0.147
Based on Median	0.704	2	6	0.531
Based on Median and with adjusted df	0.704	2	3.547	0.533
Based on the trimmed mean	2.477	2	6	0.164

Table 5. ANOVA Results for Blasting Process Time

ANOVA					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	14.38	2	7.19	735.3	0.0
Within Groups	0.05	6	0.001		
Total	14.43	8			

In addition, the results of the post hoc test used after the ANOVA for the bending test are presented in Table 6, which shows which specific groups showed significant differences.

Table 6. Results of the post hoc test of the blasting process time

Post hoc			
Tukey HSDa			
Nilai Kekasaran	**N**	**Subset for alpha = 0.05**	
		1	**2**
Copper Slag Reuse– 2	3	1.8000	
Copper Slag Reuse– 1	3	4.0667	4.0667
Copper Slag New Use	3		4.7600
Sig.		1.000	0.070

Overall, this analysis confirms that the variation of new copper slag and reused copper slag 1 and 2 is an important parameter affecting the blasting process time. Optimal blasting process time was achieved with reused copper slag-1, while a higher blasting process time was observed with new copper slag. Therefore, selecting the right copper slag variation is crucial to balance the blasting process time duration [22]. The blasting process time results are graphically depicted in Figure 9.

d. Results of the analysis of the weight of copper slag requirements

Statistical analysis was conducted to identify the significant influence of variations in the use of new copper slag and the reuse of copper slag 1 and 2 on the weight of copper slag requirements. Normality and homogeneity tests were conducted as initial steps to determine the appropriate statistical method. The results of the normality test can be seen in Table 7, while the results of the homogeneity test are shown in Table 8.

Table 7. Results of the normality test for the weight of copper slag requirements

Test of Normality						
Types of Copper Slag	**Kolmogorov-Smirnov**			**Shapiro-Wilk**		
	Stat.	**df**	**Sig.**	**Stat.**	**df**	**Sig.**
Copper Slag New Use	0.175	3		1.000	3	1.00
Copper Slag Reuse–1	0.292	3		0.923	3	0.46
Copper Slag Reuse–2	0.276	3		0.944	3	0.53

Table 8. Results of the homogeneity test for the weight of copper slag requirements

Tests of Homogeneity of Variances				
	Levene Statistic	**df1**	**df2**	**Sig.**

Based on Mean	0.184	2	6	0.836
Based on Median	0.143	2	6	0.870
Based on Median and with adjusted df	0.143	2	5.723	0.870
Based on the trimmed mean	0.181	2	6	0.839

When the data met the normality and homogeneity test criteria, Analysis of Variance (ANOVA) was applied to evaluate differences between groups. Table 9 presents the results of the ANOVA test for the copper slag weight requirement data. The ANOVA analysis results indicate that variations in copper slag have a statistically significant impact on the copper slag weight requirement.

Table 9. Results of the ANOVA test on the weight of copper slag requirements

ANOVA					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	43.947	2	21.973	72.70	0.0
Within Groups	1.813	6	0.302		
Total	45.760	8			

Additionally, the results of the post hoc test used after the ANOVA for the bending test are presented in Table 10, which shows which specific groups showed significant differences.

Table 10. Results of the post hoc test for copper slag weight requirements

Post hoc			
Tukey HSDa			
Nilai Kekasaran	**N**	**Subset for alpha = 0.05**	
		1	**2**
Copper Slag Reuse– 2	3	13.2667	
Copper Slag Reuse– 1	3	16.7333	16.733
Copper Slag New Use	3		18.600
Sig.		1.000	0.070

Overall, this study indicates that the variation of innovative copper slag usage and reuse 1 and 2 are important elements that influence the copper slag weight requirement. The most optimal copper slag weight requirement is achieved by the application of reuse-1 copper slag, while a higher copper slag weight requirement is observed with the new copper slag. Therefore, selecting the right copper slag type is crucial to achieve a balance in copper slag weight requirement [23]. The results of the copper slag weight requirement are presented graphically in Figure 10.

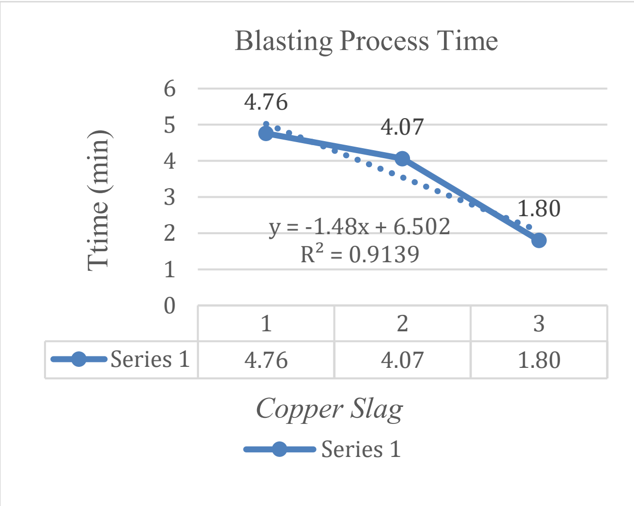

Figure 9. Graph of the blasting process time function

Based on Figure 9, the duration function graph can be explained as follows: the variables entered are copper slag (X) and the duration of the process time (Y). It is known that the new copper slag has a blasting process time of 4.76 minutes, the reused copper slag-1 has a process time of 4.07 minutes, the reused copper slag-2 has a process time of 1.80 minutes, and the results of the weight analysis of the requirements will also be depicted graphically in Figure 10.

Figure 10 shows the weight function graph, which explains that the variables entered are copper slag (X) and the duration of the process time (Y). It is known that the new copper slag yields the weight of the abrasive material required for an area of 1 m^2 of 18.6 kg, the reused copper slag-1 yields the weight of the abrasive material required for an area of 1 m^2 of 16.73 kg and the reused copper slag-2 yields the weight of the abrasive material required for an area of 1 m^2 of 13.27 kg.

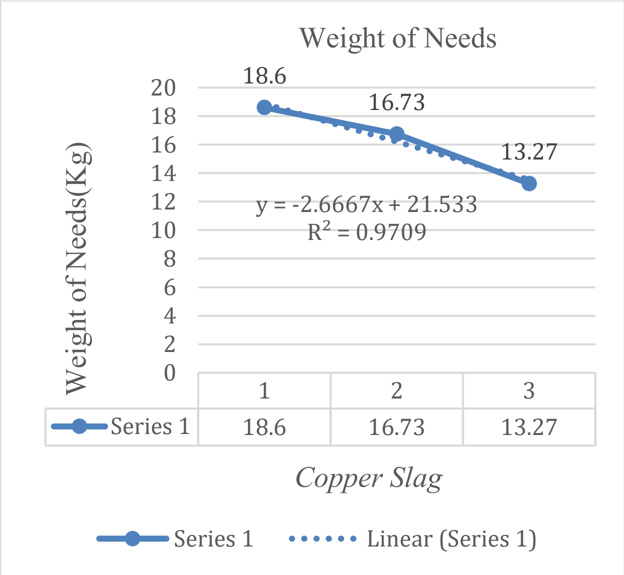

Figure 10. Graph of the weight function of copper slag requirements

Conclusion

Based on the results of research on blasting methods using variations of new copper slag, first and second reuse copper slag, it can be concluded that in the variable equation (X), namely, new copper slag and reuse copper slag-1. Blasting process time and weight requirements are variables (Y). It can be concluded that the use of new copper slag and reused copper slag-1 requires a longer blasting time, this is because the new copper slag particles still have hardness and are difficult to break. This long duration results in an increase in the weight of the abrasive material requirement, because the longer the erosion process takes place, the more abrasive volume is required.

Meanwhile, in the second reuse, copper slag with variables (X) and blasting process time, the surface roughness of the plate and the required weight are variables (Y). Although this copper slag is a second use, the copper slag for this second reuse has a more optimal blasting process time, which shows that this second-use copper slag has sharper particle characteristics when compared to the new-use copper slag. This is caused by the fragments from the previous use of copper slag and is able to clean the surface effectively without requiring excessive impact energy. This time efficiency has a direct impact on reducing the use of less abrasive material, so that the blasting process becomes more economical without reducing the quality of the cleanliness level.

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