Modification of SS 304 using semi automatic sandblasting for improvement of roughness and grade quality

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Abstract. This study aimed to discover the effect of pressure and spraying angle to surface roughness and flatness of stainless steel SUS304 after the sandblasting process. In this study, the variation of the compressor pressure were 4, 5, and 6 bar, while spraying angles were 45°, 60° dan 90°. Silica sand was used as the abrasive particles, which is sprayed onto the specimen surface. The size of silica sand was 200-300 µm. While, the sprayer feedrate was 5 cm min⁻¹ and the distance between nozzle and specimen surface was 15 cm. There were two of spraying methods, i.e., one side spraying and two sides spraying with the same pressure and spraying angle in both sides. Both spraying methods were conducted by using the support of DIY CNC equipment. The roughness test only conducted on the specimen with one side spraying. It gives the result of a higher spraying pressure increased the roughness value due to a bigger sand collision force and more sand mass that collide the surface. The sandblasting process was resulted the presence of compressive residual stress and surface elongation that caused the material become warp and producing a deflection angle. The deflection angle indicates the surface flatness quality of a material, where a smaller deflection angle means better quality of surface flatness and vice versa. Too big of a deflection angle requires a further process. This study analyzed the comparison of one side spraying and two sides spraying with the same spraying variables on both sides. It is discovered that two sides spraying produced a better surface flatness.

Keywords: sandblasting, spraying angle, roughness, flatness, deflection angle, one side spraying, two sides spraying.

1 Introduction

PT. Industri Kereta Api / INKA (Persero) engages in the manufacturing industry that focuses on train production. The produced goods from a company that runs in the manufacturing industry, such as PT. INKA (Persero) needs surface treatment to enhance particular characteristics. These treatments might be applied using mechanical, chemical, and anodization methods. From the three methods, the chemical and anodization need expensive equipment and complex process. Meanwhile, a mechanical method, such as sandblasting, seems to be more suitable [1]. This theory is supported by Shen [2], who suggested that the sandblasting process is a low-cost technology. Sandblasting has advantages over other methods from the working time, utilization, and more [3]. Though sandblasting generates likely effects on grinding, surface resulted from sandblasting is less...
rough and more uniform [4]. The ability to be flexible in following the intricate product shape is another advantage [5].

Sandblasting is the process of cleaning the surface from contaminants such as oil, salt, paint, and other materials by shooting the most general material, i.e., sand [4]. The surface is then clean because sand collides the surface and remove the contaminants. Besides cleaning the surface, the collision also creates a plastic deformation on the treatment surface [6]. The occurrence of plastic deformation caused the rough material surface after subjected to the sandblasting process [7]. Surface roughness has a significant impact in the manufacturing world because of the great role in determining the physical and chemical interaction between various matters. Surface roughness creates micro retention that increases the bond of surface and the coating material bond.

Widiyarta [6] stated that the spraying duration, compressor pressure, abrasive particle size, spraying speed, and mechanical characteristics of the material might affect the topography change angle. In another study, it is found that pressure affects more in roughness than time [8]. Surface roughness and waviness of a surface will affect the ability of lubrication spread, surface friction, heat transfer, coating, and more [9]. Nonuniformity of surface roughness is affected by a nonuniform spraying process such as the spraying pressure, shooting angle, and shooting duration. It is worth noting that constant and measured spraying will achieve a more uniform surface roughness of the working material surface [10].

Aside from the inconstant spraying, the non-flatness of a surface from sandblasting is also caused by the residual stress within the material. No material or component is free from residual stress. The presence of residual tension might benefit or harm a component’s strength [11]. A product with residual stress since before cold working manufacturing process might evoke the tensile residual stress or compressive residual stress after the manufacturing process. Residual stress can significantly affect material characteristics or a component structure, especially fatigue life, distortion, dimension, and others. Such effects require an extra cost in parts or structure repairment [12] that is undesirable by a company.

Heat treatment is a process to remove the compressive residual stress on material after the cold working manufacturing process [13] but its execution is difficult when the material or the product is a train. Besides, such a process will add the production cost and is difficult to be applied to a manufacturing company such as PT. INKA (Persero). Based on that reason, 2 sandblasting methods, i.e., one side spraying and two sides spraying, will be conducted in which these methods will be compared. It seems like one of the methods to be applied directly.

2 Methods
Sandblasting process was conducted in this study. The compressor pressure was varieted of 4, 5, and 6 bar. Furthermore, the spraying angle were 45°, 60°, dan 90° towards the specimen surface to understand the roughness and flatness quality values of stainless steel SUS304 surface and compare the one side and two sides spraying methods.

The test specimen was made from stainless steel SUS304 with size of 20 x 3.5 cm. Silica sand was used as the abrasive particle. The size of silica sand was 200-300 µm. Some equipment were used in this study i.e., rotap shaker machine, sandblasting cabinet, DIY CNC machine, sandblasting nozzle holder, specimen holder, compressor, surface roughness tester, and measuring table.
3 Results and discussion

3.1 Surface roughness
The surface testing value was obtained after conducting the testing using the surface roughness tester. The surface value data was compared to the combination of spraying pressure and angle.
Figure 4 explains the relationship between the two variables to the surface roughness of stainless steel SU304. In the sandblasting process, the pressure variables used were 4 Bar, 5 Bar, and 6 Bar, while the angles were 45°, 60°, dan 90°. Figure 5 shows that the lowest mean roughness value after the sandblasting process was obtained at the 4 bar pressure with the respective angle variables of 45°, 60°. Then, the 5 bar pressure with the respective angle variables of 45°, 60°, dan 90° for mean roughness, meanwhile, the highest mean roughness value obtained at the 6 bar pressure.

![Figure 5. Surface roughness testing results](image)

The surface roughness significantly increased following the increase in sandblasting pressure (Okada, 2019). When the pressure is high, the suction force on the hose is higher and pull more sand mass and at the same time higher spraying pressure means the sand collision force on the material surface is also higher. This is causing a deeper indentation that indicates a higher roughness value. The spraying angle affected the roughness, when the sandblasting process used 90° spraying angle, and it created a deeper indentation than the non-90° spraying angle because a friction effect before abrasive particles collide the surface and create an indentation. The resulted friction caused the collision force to be less than that of a 90°.

3.2 Surface flatness testing result data
On the flatness testing, the angle generated by the sandblasting result specimen was used. It caused by the flatness that defined as the minimum distance of two planes where each point on that surface takes place [14]. It is evident that the two planes mentioned are parallel and any flatness error will create an angle [15]. From the tests that have been done, obtained the result as in Figure 6 that discusses the effect of pressure variations and spraying angle in the sandblasting process against surface flatness using the one side spraying method and Figure 7 that shows the effect using the two sides spraying method. In the flatness testing, the smaller the deflection angle after the sandblasting process, the better the flatness quality of a specimen. In contrast, when the deflection angle value after the sandblasting process is bigger, the flatness quality is worse, where it is undesirable in the manufacturing industry.

Figure 6 explains the effect of pressure and angle towards surface flatness on the one side spraying method with pressure variations of 4, 5, and 6 bar, spraying angles of 45°, 60°, and 90°, and one side spraying. From the study, it is discovered that the higher the compressor pressure, the deflection angle obtained is also higher. But there is a difference in which the lowest deflection angle is resulted by the spraying process with 6 bar pressure and 45° spraying angle for 0.283° that shows the best flatness quality. While figure 7 explains the effect of pressure and angle towards
surface flatness on the two sides spraying method. Each side received sandblasting shooting with the same pressure and angle variations. As figure 6 that the deflection angle is bigger following the increase in spraying angle and compressor pressure, meaning that the surface flatness quality is worsening. However, same with the data of the one side spraying method, the two sides method also has a deviation where 6 bar pressure and 45° spraying angle produced the lowest deflection angle of 0.035° that shows the best flatness quality.

![Figure 6. Result of surface flatness testing with the one side spraying method](image)

It is visible that both figures have the same data tendency, where a bigger shooting angle means a bigger deflection angle. It follows the literature study by Jonchen P. Fuhr [16], stating that the spraying degree is one of the factors affecting surface flatness. Bigger deflection angle means lower flatness quality. The sand collision process as external force subjected to the material surface caused deformation and size change, such as elongated surface on the sandblasting process called stress [17]. Plastic deformation due to sand collision generates residual stress because the material tries to maintain its form [18]. Residual stress profile resulting in the surface top is the compressive residual stress, while tensile residual stress occurs within the component; it ensures the inner tension balance [19]. During the sandblasting process, plastic deformation changes dislocation density and distance between the crystal grid or may be defined as the development of compressive residual stress. In this study, the pre-studied material experienced the machining process to achieve the determined dimension. From a study by [20], when a material already has a compressive residual value and is given further process that produces compressive residual stress such as sandblasting, the compressive residual stress will increase. Sand shooting acts as a rolling pin to elongate the thin layer on top of the material. If the layer is free, it can be longer than the layer underneath it. However, since both layers are fused, the lower
layer will try to maintain its position. The effort to maintain its position corresponding to the high compressive residual strength caused the test specimen to warp upward and create a deflection angle that decreased flatness quality.

3.3 Analysis of one side and two sides spraying effect
To provide a solution for problems arising in PT. INKA (Persero), especially in facing product dimension change after subjected to the sandblasting process, this study compares 2 spraying methods. The first spraying was conducted on one side, and the second spraying was conducted on two sides alternately with the same pressure and spraying angle variations on each side. This method conducted to minimalize or remove the effect of excess compressive residual stress that causes the deflection angle on sandblasted material.

Figure 8. One side spraying, a) Material condition after adjusting the dimension, b) Material during sandblasting process

Figure 9. Two sides spraying, a) Material spraying on the second side, b) Material condition after two sides spraying

Figure 8 (a) illustrates the material condition's illustration after its dimension is adjusted before being subjected to the sandblasting process. According to the previous discussion, after the machining process, the material will possess an initial compressive residual stress. Figure 8 (b) is the sandblasting process illustration that creates compressive residual stress. The deflection angle resulted in one side spraying method seems too big, so the two sides spraying method takes place. Figure 9 (a) illustrates the second sandblasting process applied to the material subjected to a previous sandblasting process. It can be seen that on the lower part of the material, surface roughness is present due to the first spraying. On the second spraying, the compressive residual stress is also produced around the material collision. Then, Figure 9 (b) illustrates the material condition after subjected to the sandblasting process on both sides. It is obvious that both have the same surface roughness is the pressure and spraying angle variations are the same. The resulting deflection angle is less than the deflection angle from the one side spraying or in short, the deflection angle from the two sides spraying is smaller than the previous.

Figure 10 is the comparison chart between the deflection angle from one side spraying and two sides spraying. It is visible that the deflection angle from one side spraying is higher than the two sides spraying. It means that the two sides spraying produces a smaller deflection angle so that the surface flatness quality is better. As the previous discussion regarding the effect of pressure and
spraying angle of sandblasting to surface flatness, a higher deflection angle value from the sandblasting process means worse surface flatness quality. On the contrary, a lower deflection angle means better surface flatness quality. Where all deflection angle values from the two sides spraying are smaller than the one side spraying. The two sides spraying is actually trying to neutralize or balance the residual stress value within the material so that the deflection angle resulted from the previous spraying can be balanced by the latter deflection to achieve better surface flatness quality.

![Data comparison of the effect of sandblasting pressure and spraying angle between the one side and two sides spraying](image)

**Figure 10.** Data comparison of the effect of sandblasting pressure and spraying angle between the one side and two sides spraying

### 4. Conclusion

The conclusion from this study is that the pressure and spraying degree of the sandblasting process affect surface roughness and flatness. A higher compressor pressure will increase the surface roughness due to higher sand collision force and more sand mass that collides with the specimen surface. It caused a deeper indentation. Meanwhile, the 90° spraying angle produced the highest roughness value because the sand collision did not affect by friction effect, unlike the 45° and 60° spraying angle. When the collision force is not affected by the friction force, it will create a deeper indentation, meaning a higher roughness value.

Flatness quality in this study refers to the deflection angle resulted from the sandblasting process, where higher pressure and spraying angle means a higher deflection degree. A higher deflection degree indicates worse surface flatness. However, there is a deviation in this study where the variation of 6 bar pressure and 45° spraying degree produced the smallest deflection angle, meaning the best surface flatness quality. It caused by the amount of surface elongation and compressive residual stress, where warping is due to the material effort to maintain its position caused by the deformation. Nevertheless, this study did not conduct a compressive residual stress value measurement.

To reduce the deflection angle that may affect the flatness quality of a product, two sides spraying with the same parameter value on each side might be done. It aims to balance the compressive residual stress value within the material to achieve a better surface flatness quality.

This study result can be used as a review for the application at PT. INKA (Persero). Pressure and sand variations should be adjusted to the standard applied by PT. INKA. The utilization of DIY CNC supporting equipment shows that the sandblasting process with controlled parameters produced better material. However, the DIY CNC equipment design in this study cannot be applied to a big product such as train.
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