Quality improvement of SS 304 with variations in feed rate and spraying distance in semi-automatic sandblasting

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Abstract. Roughness and flatness are things to consider in metal coating and painting. Sandblasting is one method to get certain roughness on the surface of the material. Blasting that occurs in the process affects roughness, flatness, and deflection of the workpiece. The purpose of this study was to determine the effect of the sandblasting process on surface roughness and flatness in SS 304 stainless steels material using variations in feed rate and distance by applying a semi-automatic sandblasting process by controlling the nozzle motion. The spray feed rate variations were 20, 40, and 60 mm min⁻¹ and the distance variations were 100, 200, and 300 mm. The results of the test show that the smaller the feed rate and the closer the spraying distance, the higher the roughness value and the greater the deflection that affects surface flatness. The highest value occurs at a feed rate variation of 20 mm/min and a distance of 10 cm with a surface roughness value of 1.268 µm and flatness with a deflection angle formed of 1.184° one-sided treatment. In spraying experiments on two sided, improved the surface flatness with the highest deflection angle that occurs at a feed rate of 20 mm/min and a distance of 10 cm with a value of 0.737°.

Keywords: surface roughness, surface flatness, sandblasting, stainless steel AISI 304, one sided spraying, two sided spraying.

1 Introduction
In the railroad industry, stainless steel is used for the car body [1]. Where stainless steel is widely used in many applications, including construction, transportation parts, heavy industry, kitchen equipment, food industry, and medical equipment [2]. Austenitic SS is widely used in industry due to its excellent mechanical and functional properties such as high ductility and high strength, corrosion and excellent heat resistance. Type 304 steel, one of the most popular austenitic SS, has very high elongation properties of 50% [3].

In practice, this material needs a treatment process with surface preparation usually carried out on the material using coating [4]. Surface preparation can be done in different ways but sandblasting is one of the most effective ways to remove the damaged layer of the substrate surface [5].

Sandblasting can increase the adhesive strength of the coating by modifying the surface roughness, with various parameters such as grit type and size, sandblasting distance, sandblasting pressure, and sandblasting angle [6]. The abrasive material that is often used is sand, but other fine
materials can be used such as copper slag, shot, glass, metal, dry ice, garnet, and pieces of coconut shell and other plants [7]. This research uses silica sand. Sandblasting has two machining techniques, it can be done either manually or automatically [8]. Manual sandblasting is predominantly practiced in Indonesia and it can be researched regarding the parameters of automatic sandblasting.

Surface roughness is the repeated or random deviations from the nominal surface which form the three-dimensional (3D) topology of the surface [9]. As a result of the collision by these particles on the surface of the material at a relatively high speed, the material on the surface undergoes plastic deformation, and changes in surface roughness [10], a residual stress layer is formed which often forms in the subsurface. [11] and may result in early cracks in the material [12].

Residual Stress is caused due to the plastic deformation that is not uniform in a material, among others, due to uneven heat treatment, differences in cooling rates or continuous application of collisions [13]. Residual stress occurs after loading, as a result of externally applied loading, bending occurs at stress concentrations or cracks [14]. Curvature in the material after sandblasting causes the surface to no longer have good flatness. Surface Flatness is defined as the minimum distance between two surfaces where all the points on the surface [15].

This study discusses the effect of feed rate and spray distance on the semi-automatic sandblasting process on the quality improvement of SS 304 material on the surface flatness distribution and the roughness.

2 Methods and material
The received SS 304 plate has been cut into blocks with dimensions of 200 mm x 35 mm x 2 mm for testing as described in Table 1. The sandblasting process uses silica sand (SiO2) with a particle size of 400-630 µm. The sandblasting pressure is 5 bar and the spraying angle is 90° with an Ø 8 mm blasting nozzle with continuous vertical spraying as shown in Figure 1. The treatment is carried out semi-automatically using a DIY CNC tool, as shown in Figure 2 which is controlled using Arduino and the Universal Gcode Platform V2 application with a variation of feed rates of 20, 40 and 60 mm min and distances of 100, 200 and 300 mm. In the spraying treatment on two sides, the surface is sprayed with a feed rate of 80 mm min \(^{-1}\) first, then the other side is sprayed with the variations used. The sandblasting process scheme in this study can be seen in Figure 3.

| Table 1 Chemical Composition of SS304 |
|---------------------------------------|
| Compostion | C | Si | Mn | N | Ni | P | Cr |
| (%)        | 0,08 | 0,075 | 2 | 0,10 | 8 | 0,045 | 18 |

Source: Bringas[16]

Surface roughness was measured using the Mitutoyo portable surface roughness meter (Surftest SJ-210) in terms of arithmetic mean roughness (Ra) [17]. Roughness testing with the Surftest SJ-210 with measurements at 5 points for each specimen. The calculation of mean surface roughness (Ra) was used for statistical analysis to describe the trend of the test results [18]. Ra is calculated by an algorithm that measures the average area between hills and valleys and the deviation from the mean lines across the surface in the sample length. Ra is the mean area of all hill area and valley roughness profiles. [19]. Flatness measurements were carried out by means of macro observation using a macro camera, then measured the deflection angle formed on the specimen in the sandblasting process using the IMAGEJ software.
3 Results And Discussion

3.1 Surface Roughness

The surface test value is obtained after testing using a surface roughness tester. The results of the surface roughness measurement were compared with the combination of feed rate and spraying distance. Figure 4 explains the relationship between the two variables on the surface roughness of SS 304.
Figure 4 is a graph showing the results of the roughness test of sandblasting treatment using a variation of the feet rate with the spraying distance. In the graph, it can be seen that there is an effect of variation in feed rate and distance on surface roughness at SS 304, that is the greater the feed rate used, the smaller the roughness. When the spraying feed rate is increased, the nozzle motion speed will be greater, so that the time used for the abrasive particles to hit the surface will be smaller and the energy received by the material surface will be less and affect the roughness value will be smaller and vice versa. This energy includes kinetic and potential energy which has formula 1 as follows [20]:

\[ E = E_k + E_p = \frac{1}{2}mv^2 + mgh \]  

(1)

Where, \( E \) is the mechanical energy, \( E_k \) is the kinetic energy, \( E_p \) is the potential energy, \( m \) is the weight of the sand particles, \( v \) is the velocity of the abrasive particles, \( g \) is the acceleration due to gravity, \( h \) is the height. In the research of Matinilina, et al. [18] showed that when the spraying time increased, the more sand hit the surface of the material which made the surface receive more energy, making the surface of the material eroded deeper and increasing roughness. In the research of Zeighami, et al. [21] showed that if the distance given is close, the greater the roughness formed. When the given distance is getting closer, the area of spraying the abrasive material is getting smaller and there will be a concentration of the collision of the abrasive particles with a small area, so that the kinetic energy of the collision of the material that occurs will be greater [18].

In the research conducted by Menga, et al. [22] said that when the blasting distance increases, the effect of spraying from the nozzle on the particles will decrease and there is a slowdown in the smallest particles, namely those with low kinetic energy. The speed of the particles of the abrasive material will slow down (\( V_t < V_o \)) which is influenced by the amount of distance traveled on the object. When the speed of the abrasive material that hits it gets smaller on the surface which results in a smaller roughness profile or only scratches so that the roughness profile that arises is not too bad. In [23]. Because experiencing a straight motion event that changes regularly can be explained in formula 2 as follows

\[ EV_t^2 = V_o^2 - 2as \]  

(2)

Where \( V_o \) is the initial velocity of the particle (m s-1), \( V_t \) is the final velocity of the particle (m s-1), \( a \) is the deceleration that occurs on the object (m s-2), \( s \) is the distance traveled by the object (m)

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**Figure 5** Effect of Roughness on Manual and Automatic Treatment
Figure 5 is a graph showing the results of the effect of manual and automatic treatment on the distribution of surface roughness using a 30 cm distance variation with 5 test points, namely points A, B, C, D and E showed in Figure 6, it can be seen that the manual treatment graph has a surface roughness distribution that tends to be uneven from one point to another. This happens because during the spraying process the nozzle movement is not constant, where on one side the movement tends to be fast and on the other hand the movement tends to be slow.

Whereas for the automatic treatment graph, the surface roughness tends to be evenly distributed because the spraying process uses a DIY CNC tool whose movement can control the sandblasting feed rate so that the nozzle movement becomes constant. The impact of SiO2 particles during sandblasting changes the surface structure. A rough but homogeneous surface is formed after sandblasting [24].

3.2 Surface Flatness
Observation of surface flatness testing using the ASTM A1030 standard was carried out using macro photo observations. In the sandblasting test on one side as in Figure 7 and in the two-sided treatment in Figure 12, it can be seen that the comparison of deflections that occurs using variations in feed rate and distance.

Based on Figure 7, the greater the feed rate used, the better the resulting flatness and the smaller the deflection. When the spraying feed rate is smaller, the time used for the abrasive particles to hit the surface will be bigger and the closer the spraying distance will cause collision concentration and the effect of air pressure from the compressor will be greater which causes the collision of the
material bigger. Higher mean velocities yield higher kinetic energy than the particles may be sufficient to create surface plastic deformation [24].

In Ding, et al. [19] research showed that repeated shock loads due to high velocity sand collisions on the surface cause local plastic deformation. Plastic deformation during the sandblasting process results in the formation of residual compressive stress on the metal surface due to the collision of high-speed silica sand particles [25]. In Smith's research [13] states that residual stress is caused by non-uniform plastic deformation in a material due to continuous impact. In the study of Lai et al. [26] shows that the longer the collision process of the peening material on the 304 material surface will increase the residual compressive stress. And in the study of Zhang et al. [27] shows that the faster the impact of the abrasive material, the residual stress that is formed is greater.

Since the plastic deformed surface area is elastically limited by the material just below the surface area, the residual compressive stress generated in the surface layer is generated by sandblasting in the shallow surface layer of the material, while the residual low compensating tensile stress spreads deeper into the material [11]. The plastic deformation and residual stress generated on one side of the stainless steel plate bends the sheet material as shown in Figure 8.

Bending specimens undergo plastic deformation on their surface. This occurs after the external stress is removed after the impact, in areas that have been plastically deformed preventing the adjacent elastic region from experiencing full elastic recovery to its original state, the elastically formed area is left in the residual tensile, and the plastic deformed area must exists in the residual state of compressive stress to balance the stresses in the cross-section of the specimen [28].

In the research of Caravaca, et al. [29] stated that the residual distribution of compressive stress is more localized on the surface after blasting and a smaller Vol. of residual tensile stress in the lower layer is formed where cracks can occur. A graphical representation of the residual stress on the surface is shown in Figure 9.

Figure 8. 304 Stainless Steel after Sandblasting on one side

Figure 9. Graphical representation of [29]

Figure 10. Flatness Results In One-Sided Spraying (A.) Distance 100mm (B) 300mm
Figure 11. Flatness Results In Two-Sided Spraying (A.) Distance 100mm (B) 300mm

Figure 12. Effect of Feed Rate and Spraying Distance on Surface Flatness

Figure 13 is a graph showing the results of the flatness test on the spraying treatment on both sides. It can be seen in the graph that the greater the feed rate used, the better the flatness and smaller deflections. When the spraying feed rate is increased, the nozzle motion speed will be greater so that the time used for the abrasive particles to hit the surface will be smaller, so that the energy received by the material surface will be less and affect the flatness will be smaller and vice versa. In the sandblasting treatment on both sides with a variation of the feet rate of 40 mm min-1 and 60 mm min-1 with a distance of 200 mm and a variation of the feet rate of 20 mm min-1, 40 mm min-1 and 60 mm min-1 at a distance of 300 mm, there is an improvement in flatness possibly due to residual stress in both side of the stainless steel surface so that it balances each other.
Figure 13. Comparison of One-Sided and Two-Sided Treatment Flatness

The comparison of the deflection of one and two sides of the treatment can be seen in Figure 14, where flatness is improved due to plastic deformation and the effect of residual stress on both sides of the stainless surface resulting in balancing on both sides. As for the improvement of flatness due to sandblasting treatment on both sides of the stainless steel surface compared to one-sided treatment.

4. Conclusion
Based on the results of the research, the variation of the feed rate in the sandblasting process has an effect on surface roughness and flatness where the higher the feed rate is given, the roughness value will decrease and the deflection will be smaller and the flatness will be better. The variation in distance also has a significant effect, where the farther the spraying distance in the sandblasting process, the lower the surface roughness and the smaller the deflection and the better flatness.

Manual and automatic treatment has a significant effect on the distribution of surface roughness values where manual treatment has a surface roughness value distribution that tends to be uneven between one point and another, whereas for automatic treatment it has a surface roughness values distribution that tends to be evenly distributed with a value almost the same surface roughness at each test point. For the sandblasting treatment on both sides of the surface, it has an influence on changes in surface flatness where the deflection is smaller than the one-sided treatment.

5. References
[1] International Stainless Steel Forum. 2017. Railcars in Stainless Steel a Sustainable Solution for Sustainable Public Transport. Burssels, Belgia.
[2] Lin C. W., 2016. Morphological effect governed by sandblasting and anodic surface reforming on the super-hydrophobicity of AISI 304 stainless steel. Thin Solid Films. Vol. 620 pp: 88-93.
[3] Ishimaru E., Hamasaki H., Yoshida F. 2014. Deformation-induced Martensitic Transformation and Workhardening of Type 304 Stainless Steel Sheet During Draw-bending. Procedia Engineering Vol. 81 pp: 921–926.
[4] Bahadori A. 2015. Engineering and Technical Guidelines for Painting. Essentials of Coating, Painting, and Lining for the Oil, Gas and Petrochemical Industries. Chapter 2 pp: 107-156.
[5] Khorasanizadeh S.2010. The Effects of Shot and Grit Blasting Process Parameters on Steel Pipes Coating Adhesion. International Journal of Industrial and Manufacturing Engineering Vol. 4
[6] Jian L.2018. Improvement of Aluminum Lithium Alloy Adhesion Performance Based on Sandblasting Techniques. International Journal of Adhesion and Adhesives Vol. 84 pp:307–316.
[7] Widodo, T. D, Raharjo, R., Sugiono, Wahyudiono, A, 2018. Effect of Low Temperature Steel Ball Peening on the Hardness of SS 316L, Key Engineering Materials, Vol. 791, pp. 105-110.

[8] Raharjo,R., Kusumaningsih, H., Widodo T.D., Bintarto, R., Widiasesanti, M., Pramudia, M. 2019.,Word Enhancement of Tongue Depressor Hardness by Heat Treatment and Shot Peening, IOP Conference Series: Materials Science and Engineering, IOP Publishing, Vol 494.

[9] Jiang X.P., Wang X.Y., Li J.X. 2006 Enhancement of Fatigue and Corrosion Properties of Pure Ti by Sandblasting. Materials Science and Engineering A Vol. 429 : 30–35.

[10] Rudawska et al. 2016. The Effect of Sandblasting on Surface Properties for Adhesion. International Journal of Adhesion and Adhesive.Vol. 70 : 176-190.

[11] Darmadi, D.B.; Abdillah, F.N.; Raharjo, R. 2019 Controlling the pressure force to obtain a better quality of aluminum 6061 friction stir welded joint. East.-Eur. J. Enterp. Technol. 3, 6–10.

[12] Haitjema, H. 2014. Flatness. CIRP Encyclopedia of Production Engineering, 1–5.

[13] Bringas J. E. 2014. Handbook of Comparative World Steel Standart. Thirth Edition ASTM International USA.

[14] Diraj Sayyed, Dharmadikari, H.M. 2018. Modeling of Roughness Value from Tribologi Parameter in Hard Turning of AISI 52100 Steel. Procedia Manufacture Vol. 20:344-349.

[15] Matinlina J.P. 2015. Effects of sandblasting distance and angles on resin cement bonding to zirconia and titanium. Vol. 62 pp: 25–31

[16] Ding L., Torbati-Sarraf H. 2018. The Influence of the Sandblasting as a Surface Mechanical Attrition Treatment on the Electrochemical Behavior of Carbon Steel in Different pH. Solutions Surface & Coatings Technology. Vol. 352:112–119.

[17] Gupta M., Nguyen, Q.,B.. 2014. Effect of Impact Angle and Testing Time on Erosion of Stainless Steel at Higher Velocities. Wear Vol. 321 : 87–93.

[18] Zeighami S., (2017). Effect of Sandblasting Angle and Distance on Biaxial Flexural Strength of Zirconia-based Ceramics. The Journal of Contemporary Dental Practice. : 443-447.

[19] Menga N., Mundo R. D., Carbone G. 2017. Soft blasting of fluorinated polymers: The easy way to superhydrophobicity. Materials and Design Vol. 121: 414–420.

[20] Chen H. 2018. Simulation and experimental validation of residual stress and surface roughness of high manganese steel after shot peening. 4th CIRP Design Conference. Procedia CIRP. Vol. 71 pp:227–231

[21] Bouledroua O., Meliani M. Hadj. 2017. Effect of Sandblasting on Tensile Properties, Hardness and Fracture Resistance of a Line Pipe Steel Used in Algeria for Oil Transport. J Fail. Anal. and Preven. ASM International 2017.

[22] Chintapalli R. K., Rodriguez A. M. 2014. Effect of sandblasting and residual stress on strength of zirconia for restorative dentistry applications. Journal of the mechanical behavior of biomedical materials Vol. 29 : 126–137

[23] Lai H. H., Cheng H. C., Lin C. M., Wu W. 2020. Effect of shot peening time on δ/γ residual stress profiles of AISI 304 weld. Journal of Materials Processing Tech. 284

[24] Zhang Y., Lai F., Qu S. (2020). Effect of Shot Peening on Residual Stress Distribution and Tribological Behaviors of 17Cr2Ni2MoVNb steel. Surface & Coatings Technology 386

[25] Caravaca C. F. 2018. Impact of sandblasting on the mechanical properties and aging resistance of alumina and zirconia based ceramics. Journal of the European Ceramic Society. Vol. 38 pp: 915–925.

[26] Dieter George E. 1961. Metallurgy and metallurgical engineering series. New York. Jr.-Mechanical Metallurgy-McGraw-Hill