The impact of sand particle size and velocity on sand erosion of stainless steel plate using sand blasting technique

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Abstract

Economic considerations determine the selection of low-cost steel material such as carbon steel in oil and gas industry. However, there are situations where carbon steel is replaced by stainless steel especially when encountering aggressive brines that contains weak acid such as acetic acid. Stainless steel is known for its corrosion resistance. However, the erosion resistance of stainless steel is not well understood. The purpose of this paper is to investigate the effect of sand particle size and velocity on the stainless steel erosion rate using sand blasting technique. Scanning Electron Microscope and Universal Scanning Probe Microscope were used to evaluate the erosion on the surface of the plates. The experimental results revealed that larger sized sand particles and higher gas flow velocity caused more severe erosion on the surface of the plates. The severity of the treated stainless steel plate was represented using the USPM cross sectional micrograph. The medium sized sand particles can cause 25^o deep crater compared to fine sand with only 7^o deep crater. Besides, high sand impact velocity of 22 m/s caused more erosion of 13^o depth in the USPM cross sectional micrograph compared to 17 m/s which causing 7^o deep erosion in the USPM micrograph.

Keywords
Sand impact erosion, stainless steel, sand size, sand velocity, sand blasting technique

1. Introduction

Sand production is a common issue especially in weak, unconsolidated sandstone reservoir during oil and gas abstraction. The sand particles can be detached from the reservoir and are produced during the extraction of oil, water or gas. Sand production may occur at the very beginning of the flow or later when the reservoir pressure has fallen or water breakthrough (Carlson, Gurley, King, Price-Smith, & Waters, 1992). Not all sand production needs action depending on its degree of severity and sometimes, continuous sand production is tolerated. Being known as one of the toughest oil and gas production related problem, sand production is the main cause of many flow assurance problems which include sand impact erosion (Islam & Farhat, 2014). Erosion is defined as the material loss from the metal surface that is impacted by a flowing fluid which carries tiny solid particles with a sequence of mechanical actions (M. Y. Naz, Ismail, Sulaiman, & Shukrullah, 2015; Rauf & Mahdi, 2012). Erosion can cause severe damage to pipelines, disable production and surface equipment. Many cases have been previously reported in the past where catastrophic accident happens due to sand impact erosion in flow lines as shown in Figure 1.

Figure 1. Illustration of severely damaged flow-lines caused by erosion (M. Y. Naz et al., 2016b)

Several numerical and empirical models have been made to predict sand impact erosion with several factors such as sand particle size, impact angle, impact velocity and type of material in consideration (M. Y. Naz et al., 2016a). It was reported that erosion process is mostly influenced by the particle size and amount of particle hitting the surface. Small sand particles (~10 um) are often carried away together with the fluids and rarely impact the pipe surface. On the other hand, medium sized particles move in a straight line and bounce off the target surface (M. Naz et al., 2017). Gandhi & Borse, (2002) conducted an experimental investigation on erosion rate of cast iron in sand-water mixtures and concluded that erosion rate increases almost linearly with increase in particle size. This is because the erosion rate is proportional to loss in kinetic energy of the solid particles impacting at the target surface. The kinetic energy of the solid particle is directly proportional to the particle mass.

Apart from that, sand impact erosion is also affected by the transport velocity. Normally, gas flow systems operated at a velocity higher than 10 m/s, which causes this system more prone to sand impact erosion compared to liquid flow system. Conversely, in low flow condition, the sand will settle out of the flow, accumulate along the pipelines and can only be flushed out when the system is operated at high velocity. Theoretically, low particle velocity will cause a small fraction of the particles have enough velocity and mass to cause plastic deformation to the steel surface. The majority of the particles have lower energy, below a threshold value which only causes elastic deformation of the steel. As particle velocity increases, more particles acquire the required critical energy to cause deformation and material removal.

This article will focus on the sand impact erosion on stainless steel plate due to sand flow using sand blasting technique qualitatively and quantitatively. The main objectives are to investigate the effect of sand particle size, medium size sand and fines sand on the stainless steel plate and the impact of velocity at 17 m/s and 22 m/s on the erosion of the stainless steel plate. The eroded stainless steel plates were characterized using scanning electron microscopy and universal scanning probe microscopy.

2. Material and methods

Dry sieving method was used to segregate the medium-sized sand (63 µm to 150 µm) and fine sand (< 63 µm). A series of sieve mesh stacked following mesh size of 600 µm, 425 µm, 300 µm, 250 µm, 150 µm, and 63 µm. The sand sample was placed on the stacked mesh and was seeped through the screen until it faces the screen with openings smaller than the desired grain size. Mechanical vibration was also applied to the stacked sieve mesh to further promote the seeping process. The sand type used in this study was sandstones: a clastic sedimentary rock of sand-size particles, which was used as an erosion agent for flow-lines erosion.

Sand blasting technique at room temperature was used to simulate the bombardment of the sand particles onto the stainless steel plant whereas the stainless steel (SS 304) plates represent the inner surface of the production flow-line. The schematic diagram of the sand blasting test rig is shown in Figure 2. The sand blasting test rig consists of an air blower, sand feeder and a metal plate holder. The air blower with the maximum air flux of 120 m^3/h was used to accelerate the sand particles on the stainless steel plate. Prior to the test, the sand particles were placed in the sand feeder while the stainless steel plate was attached to the metal plate holder.

The impingement angle was kept constant at 90º throughout the experiment. This will simulate the flow condition at T- junction of the pipeline. In addition, the distance between the nozzle and the stainless steel plate was also kept constant at 10 mm throughout the experiment. The stainless steel was exposed to the bombardment for a fixed time interval of 2 hours. The stainless steel plate was bombarded at different sand particle velocity (17 m/s and 22 m/s) and with different sand particles (medium and fine sand). The untreated and treated stainless steel was analysed with scanning electron microscopy (SEM) and universal scanning probe microscopy (USPM).

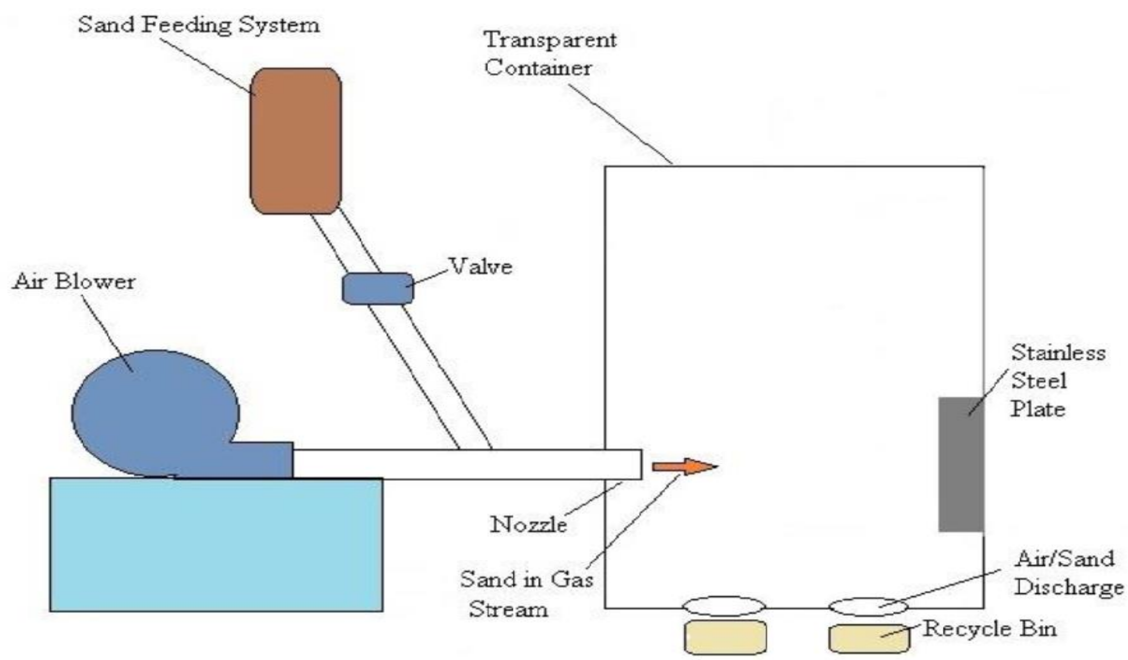

Figure 2. Schematic diagram of the sand blasting test rig

3. Results and discussion

In this study, the effect of sand particle size and velocity on stainless steel plate was investigated for a better understanding of the sand impact erosion of the flow–lines. The abrasive erosion of the stainless steel plate was carried out using sand blasting test rig which is more likely to be a physical phenomenon rather than chemical process. The SEM image of the untreated stainless steel at 300 times magnification is shown in Figure 3. From the image, it can be observed that the untreated stainless steel plate is clean without any erosion mark on it. There are no significant scratches and dented mark observed on from the SEM image. Figure 4 shows the USPM results of the untreated stainless steel plate at 1000 nanometres. It was found that the highest average tip for the untreated stainless steel plate was 306.5º while the lowest tip was 306.3º respectively. It was found that slight changes in the tip difference of the USPM cross-section, but the deepest is only 0.2° against the normal plane while there is no significant wide crater observed along the normal plane. It might be due to the poor handling while preparing the plate but does not give significant disturbance to the readings of the treated samples. The severity of erosion for each scenario can then be clearly determined as there is no external erosion acting on the plate before it was treated with sandblasting.

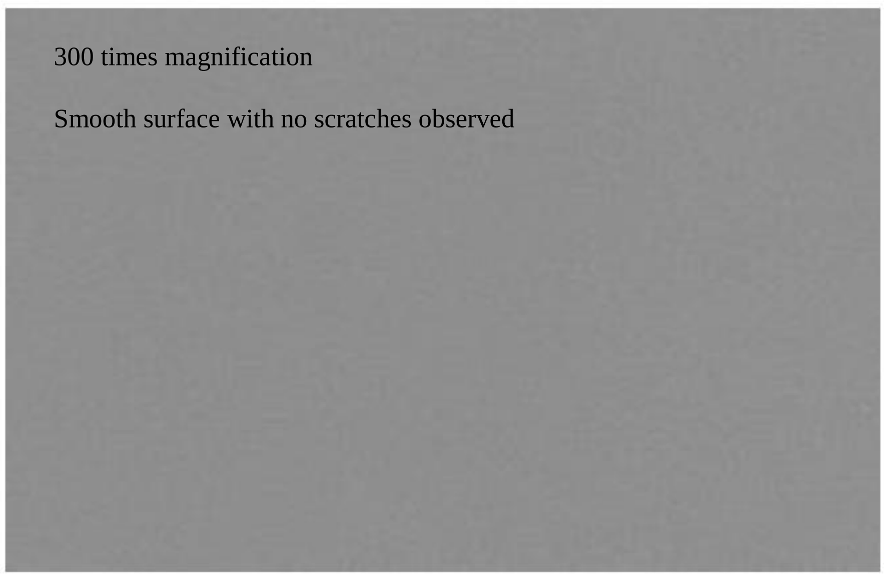

Figure 3. SEM image of untreated stainless steel at 300 times magnification

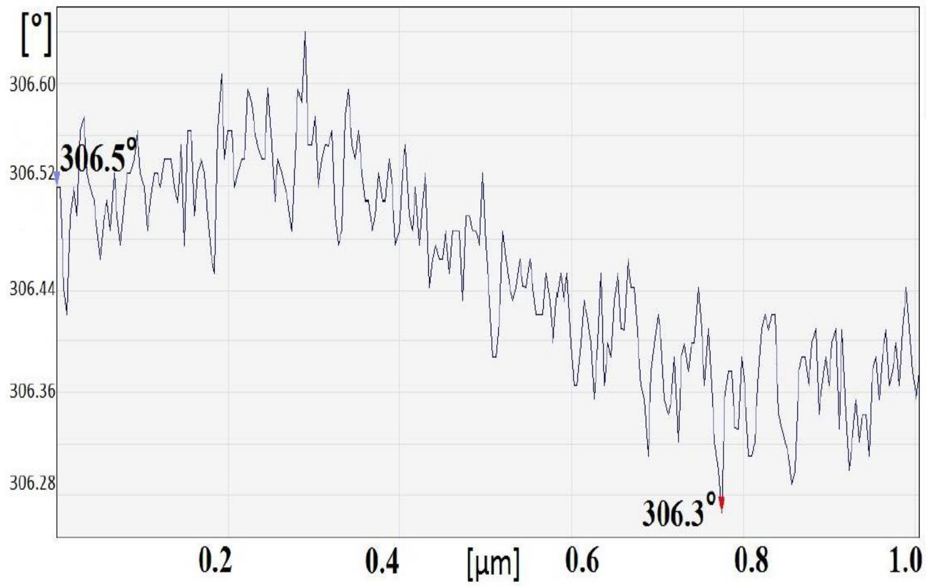

Figure 4. USPM cross section profile of untreated stainless steel

The effect of the sand particle size on the stainless steel plate was investigated using SEM and USPM. The stainless steel plate was bombarded for 2 hours using medium and fine sand at 17 m/s. The SEM images of treated stainless steel at 300 times magnification are shown in Figures 5 and 6. It can be observed that dark and rough patches appear at the surface of the stainless steel treated with both medium and fine sand. The surface for both treated stainless steel place appeared uneven and the change in colour were significant. This changes revealed changes in the surface morphology of the treated stainless steel plates. By comparing the cross-sectional profile of the models, the craters for medium-sized sand erosion is bigger and deeper compared to the craters in fine sand erosion as shown in Figures 7 and 8. It was observed that erosion by medium-sized sand was 0.3 μm wide with tip difference of 25.1° from the normal plane. While for fine sand erosion, the pattern of the craters is close to each other but not as wide as in medium-sized sand erosion and even the deepest crater only gives tip difference of 7.0° from the normal plane. It shows that the medium size sand eroded the stainless steel plate more deeply compared to fine sand. This is because bigger particle size will have larger inertia and momentum (Gandhi et al, 2004; Guo et al, 2005). With higher momentum, the particles will be harder to stop, thus producing higher impact energy when they collide with the surface of the metal plates. Therefore, material loss will be more and erosion severity will be higher as the particle size increases. Besides, for medium-sized sand almost all particles were involved in removing the material from the surface due to minimum interference between incoming and rebounding particles. The collisions between incoming particles and the rebounding particles significantly reduced the kinetic energies of the particles approaching the target. This interference was an energy barrier for the incident particles impacting on the sample.

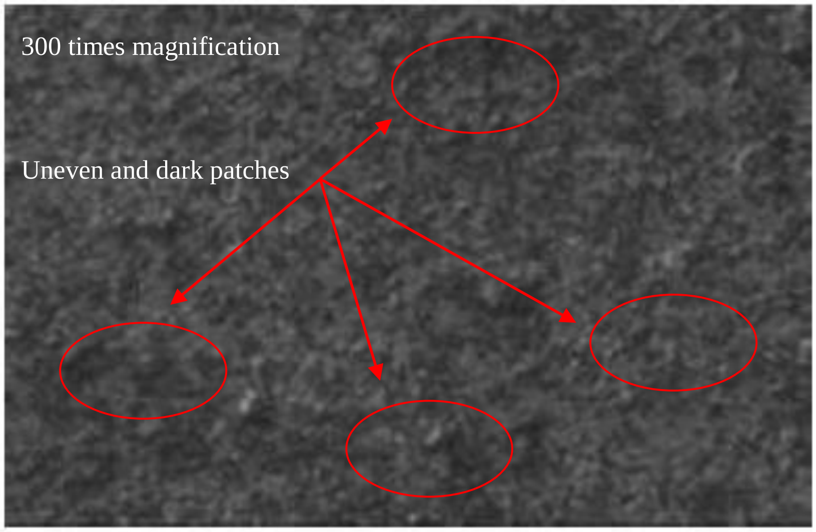

Figure 5. SEM image treated stainless steel sample bombarded with fine sand at 300 times magnification

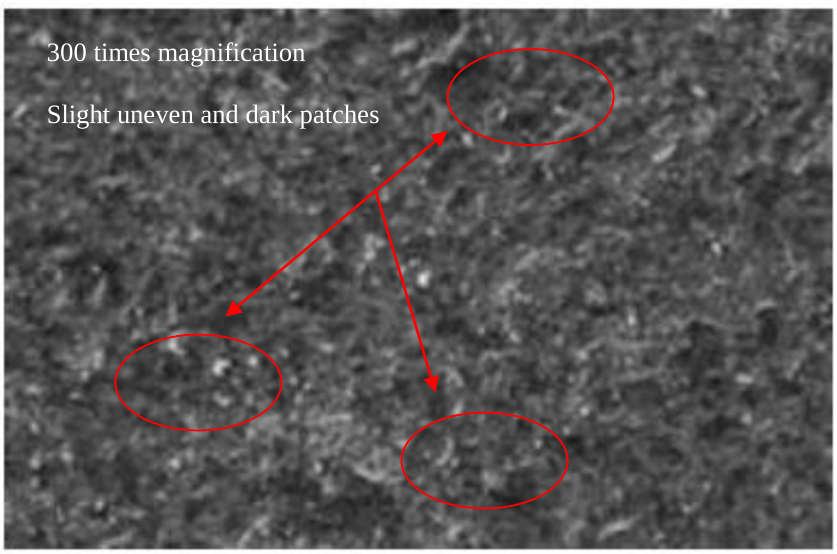

Figure 6. SEM image treated stainless steel sample bombarded with medium size sand at 300 times magnification

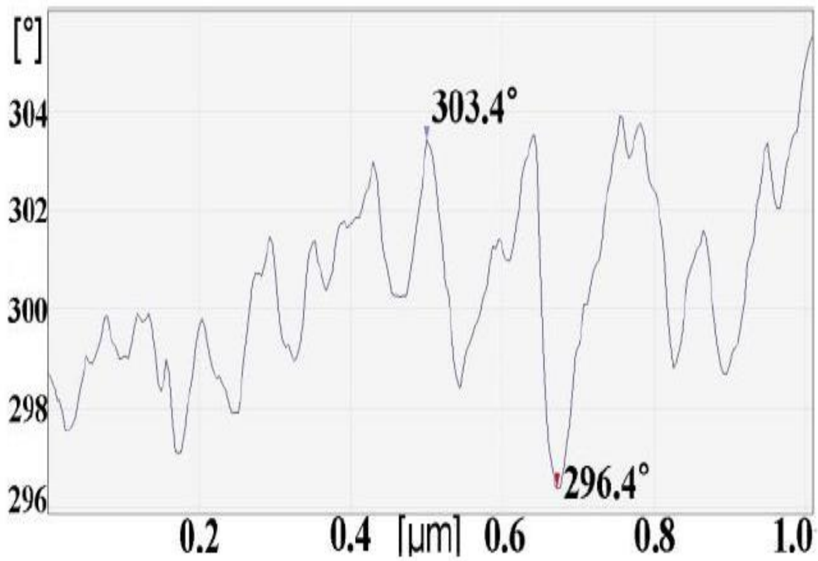

Figure 7. USPM cross section profile of treated stainless steel bombarded with fine sand

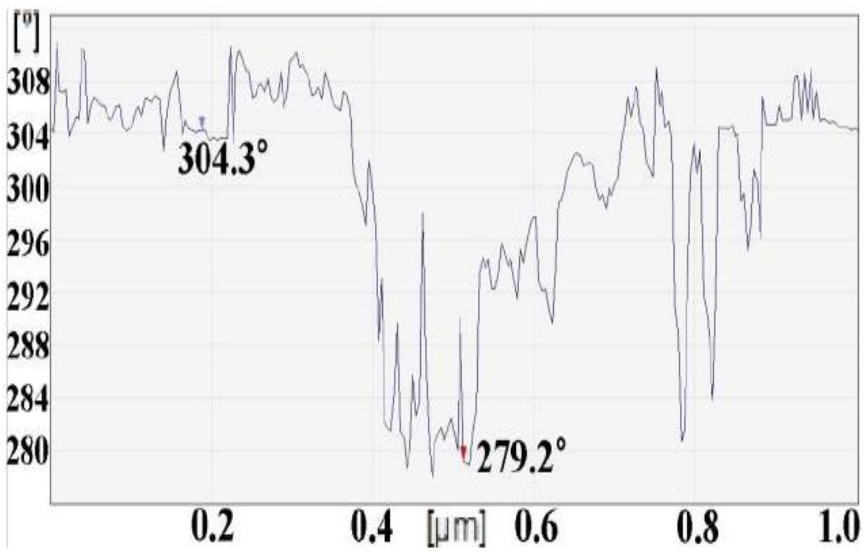

Figure 8. USPM cross section profile of treated stainless steel bombarded with medium size sand

SEM image in Figures 9 and 10 reveal the impact of bombardment with fine sand at 17 m/s and 22 m/s velocities at 300 times magnification. It was observed that exposed surface becomes dark revealing a high level of roughness. It appeared that at 22m/s, the dark region was more prominent thus the erosion of the stainless steel was more compared to 17 m/s. This observation was supported by the USPM result as shown in Figures 11 and 12. According to the USPM cross-sections, the craters in erosion from 22 m/s velocity particles are wider compared to the craters from erosion with 17 m/s velocity particles. The craters in erosion with 22 m/s velocity particles are as deep as 13° tip differences with the normal plane, compared to the craters in erosion with 17 m/s particles, which only yield around 7° tip differences with the normal plane.

Therefore, it can be concluded that the cross sectional profiles of the eroded stainless steel plate showed that the impact or crater created by the high velocity sand were wider and deeper (Gupta, Singh, & Sehadri, 1995; Islam & Farhat, 2014; M. Naz et al., 2017). When the particle velocity is low, thus, low kinetic energy, only small fraction of the particles has enough velocity and mass to cause plastic deformation to the steel surface. The majority of the particles have lower energy, below a threshold value which only causes elastic deformation of the steel. As particle velocity increases, more particles acquire the required critical energy to cause deformation and material removal. It also has been noticed that collision efficiency decreased with a decline in particle velocity (Habib et al, 2007; Salama et al, 2000). Quantitatively, a decrease in collision efficiency and consequently the erosion can be attributed to the lower momentum of the sand particles.

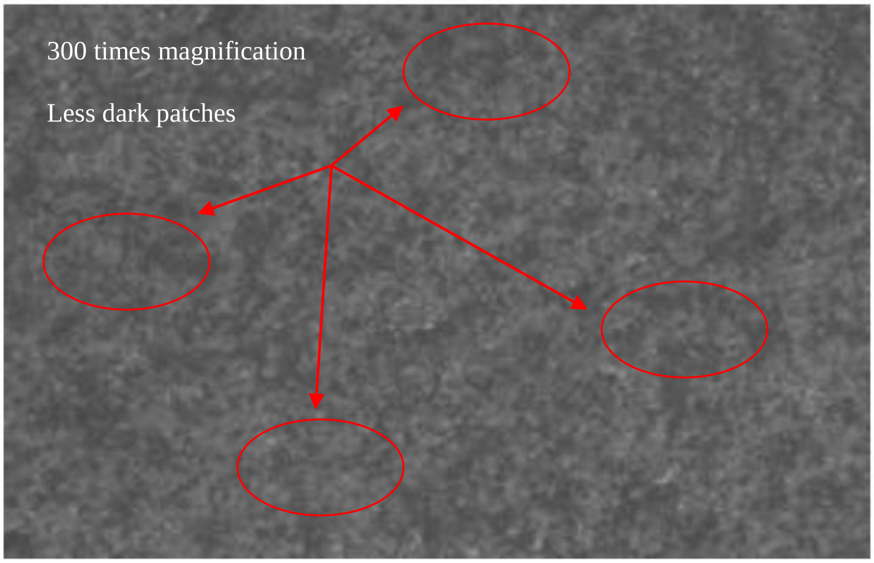

Figure 9. SEM image of treated stainless steel sample bombarded with fine sand at 17 m/s at 300 times magnification

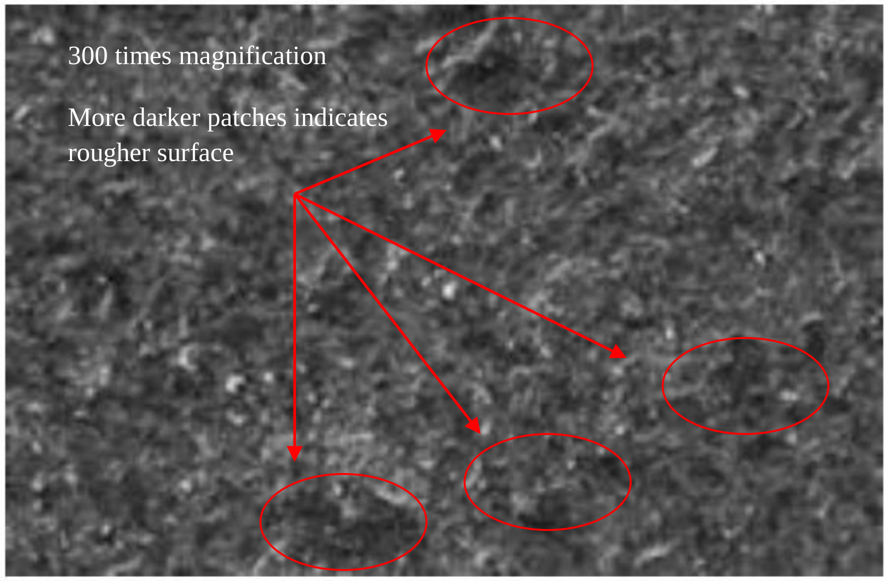

Figure 10. SEM image of treated stainless steel sample bombarded with fine sand at 22 m/s at 300 times magnification.

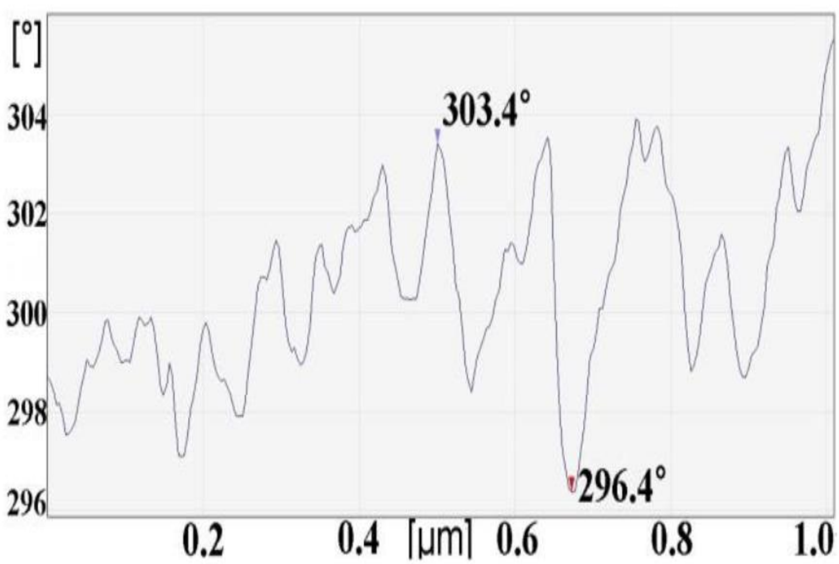

Figure 11. USPM cross section profile of treated stainless steel bombarded with fine sand at 17 m/s

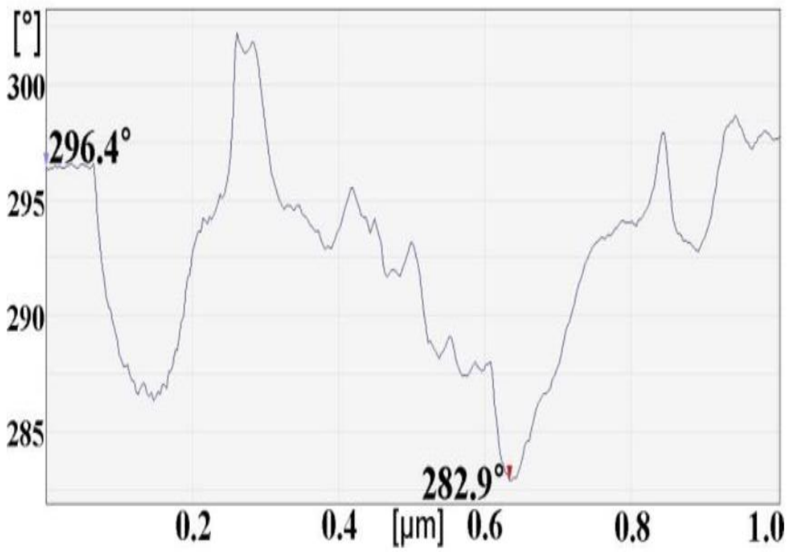

Figure 12. USPM cross section profile of treated stainless steel bombarded with fine sand at 22 m/s

4. Conclusion

This study investigated the effect of sand particle size and velocity on the erosion of stainless steel plate using sand blasting technique. The effect of particle size on the stainless steel erosion was elaborated in two sand particle sizes: medium sand size (63 μm to 150 μm) and fine sand (<63 μm). It was found that the bigger the sand, the more severe the erosion caused on the surface of the facilities and equipment. USPM micrograph results show that the erosion caused by medium sized particle was deeper compared to the erosion caused by fine sand (25.1^o and 7^o respectively). Apart from that, the sand particle accelerated at 22 m/s eroded the stainless steel plate more severely compared to the particle hitting the stainless steel surface at a velocity of 17 m/s. The USPM cross sectional result shows that higher velocity sand, 22 m/s can erode the stainless steel 13^o deep compared to 17 m/s sand particles which eroded the stainless steel plate with only 7^o.

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