

Topography between contact surfaces in slip resistant bolted joint

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Abstract

Within the RFCS project SIROCO, TU Delft has performed trials to measure friction in stainless slip resistant bolted joints. The aim with this examination is to characterise the appearances of the contact surfaces after the slip factor test.

- The austenitic A- Grit sample which is Core 304L is softer than the duplex and super duplex samples, which are Forta DX 2205 and Forta SDX 2507. This is demonstrated by the higher Ra-values from the reference area A1, and is also visualised in the examination from the confocal microscope.
- The grit blasted duplex and super duplex grades in sample D- Grit have the lowest surface roughness difference between reference area and contact area.
- The coefficient of friction measured in the slip factor test is suggested to be due to a combination of cold welding and mechanical interlocking of surface asperities.

Key words: Surface defects, Mechanical properties, Hardness, Friction

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1. Introduction

Within the RFCS project SIROCO, TU Delft has performed trials to measure friction in stainless slip resistant bolted joints. The aim with this examination is to characterise the appearances of the contact surfaces after the slip factor test.

2. Materials

Test materials were sent to ARC for examination, the stainless steel grades were: Core 304L (1.4307), Forta DX 2205(1.4462), and Forta SDX 2507(1.4410).

The materials had been set up in a slip resistant bolted joint similar to the real application according to EN 1090-2, Annex G, comparing different surface treatments grit blasted and shot blasted [1]

Test materials were named and sorted as below, where area A1 is a reference area that hasn't been in any contact, areas B1 and E1 are deformed after contact according to the sketch in figure 1:

D_40_2 = "Duplex" shot blasted surface: Forta DX 2205 area A1, E1. Forta SDX 2507 area B1. Will be called D-Shot from now on.

D_50_2 = "Duplex" grit blasted surface: Forta DX 2205 area A1, E1. Forta SDX 2507 area B1. Will be called D-Grit from now on.

A_50_3 = "Austenite" grit blasted surface: Core 304L all areas. Will be called A-Grit from now on.

Figure 1 shows the screw joint in position, with the examined areas marked. The arrow shows the direction of the mechanical stresses applied to the samples.

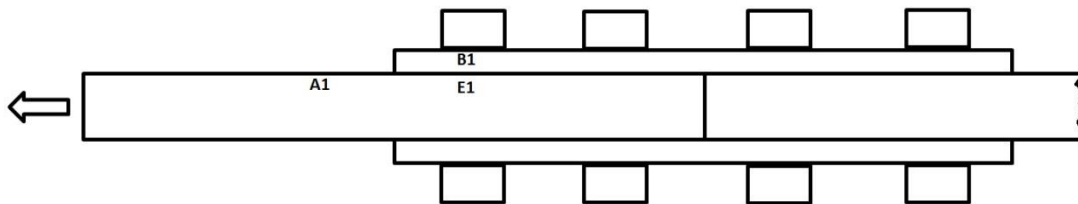


Figure 1 Shows a sketch of the screw joint, and where the different areas are placed on the samples. The arrow shows how the mechanical stresses were applied.

3. Experimental technique

The samples were cut off for examination in the confocal microscope, where the 20X magnification lens was used.

The areas of examination on the samples are all close to the drilled hole with an attempt to identify faying surfaces, except the reference area A1 which is the original shot/grit blasted surfaces.

The Ra surface roughness was measured with a mechanical stylus instrument on the samples on reference area A1, and on the areas B1 and E1 which had been slightly deformed by friction from the joint during the slip test. Rz-values were derived from the work made at TU Delft [1].

The surface hardness was estimated in HRC with an Equotip device using a load of 5,5g

4. Results

The pictures from the confocal microscope are all in the same scale, and two colour schemes. The colour schemes that were used are Photorealistic and Fire for comparison of visual roughness and measurable roughness on the surface. There are two 3D pictures of each area; one in photorealistic colour and one in Fire colour scheme with a scale bar. There are also plane views of each area in photorealistic colour scheme, showing an overview of the tested areas. Ra-values of the tested areas are shown in table 1.

Figures 2 -8 show all reference areas A1 in both photorealistic and Fire colour schemes for comparison. Figure 5 shows the scale bar for the Fire colour schemes.

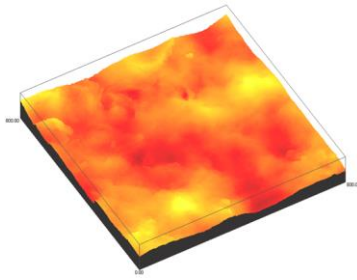


Figure 2 Area A1 from the D-Shot sample in Fire colour scheme. Ra: 5,37 μm , Rz:36 μm

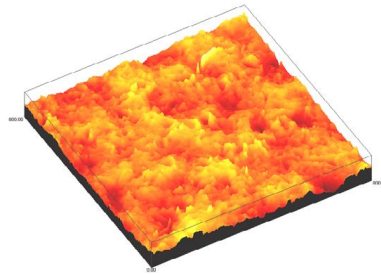


Figure 3 Area A1 from the D-Grit sample Fire colour scheme. Ra:5,44 μm , Rz:44 μm

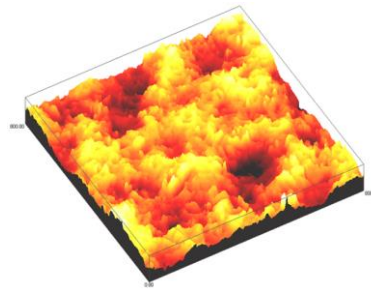


Figure 4 Area A1 from the A-Grit sample Fire colour scheme. Ra:9,37 μm , Rz:58 μm

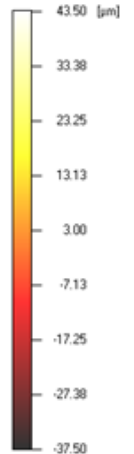


Figure 5

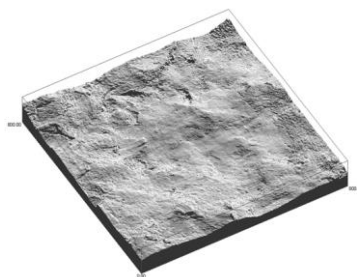


Figure 6 Area A1 from sample D-Shot in photorealistic colour scheme.

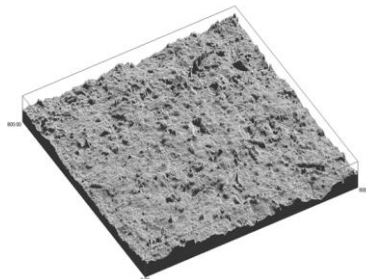


Figure 7 Area A1 from sample D-Grit in photorealistic colour scheme.

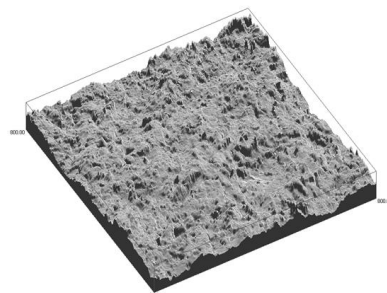


Figure 8 Area A1 from sample A-Grit in photorealistic colour scheme.

Figures 9-13 shows areas B1 and E1 from sample D-Shot in both photorealistic and Fire schemes. Figure 11 shows the scale bar for the Fire colour schemes.

As indicated by the roughness values, A-grit has the roughest surface and D-shot the least rough surface, as indicated by the roughness values. What is obvious from the 3D pictures (Figure 1-8) is also that the grit blasted surfaces have a "sharper" asperity appearance, while the shot blasted is blunter.

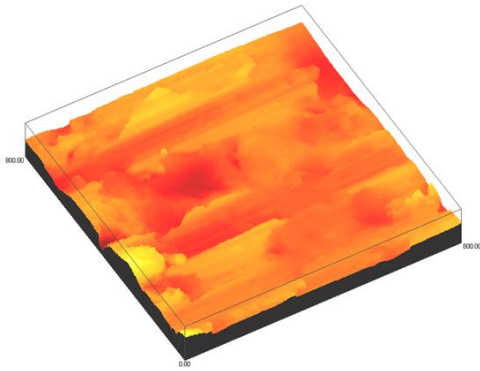


Figure 9 Area B1 from the D- Shot sample in Fire colour scheme. Ra: 4,70

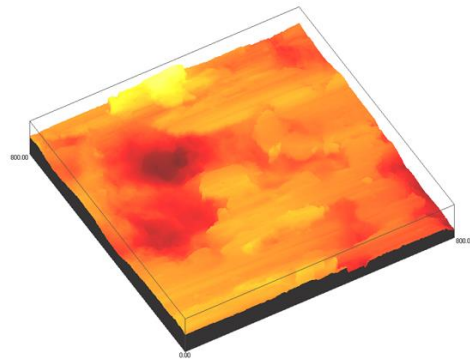


Figure 10 Area E1 from the D- Shot sample in Fire colour scheme. Ra: 4,92

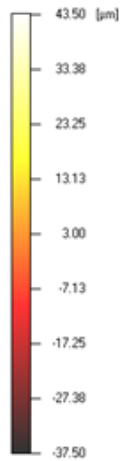


Figure 11

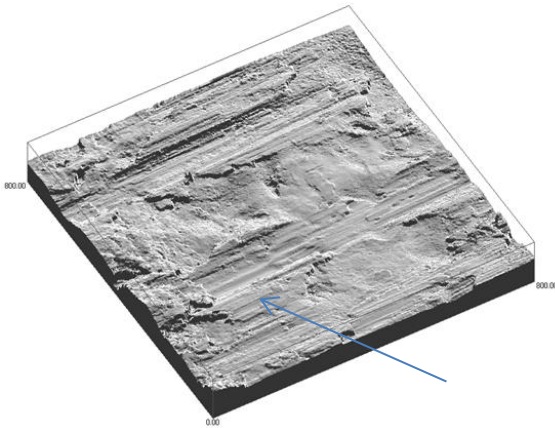


Figure 12 Area B1 from sample D- shot in photorealistic colour scheme.

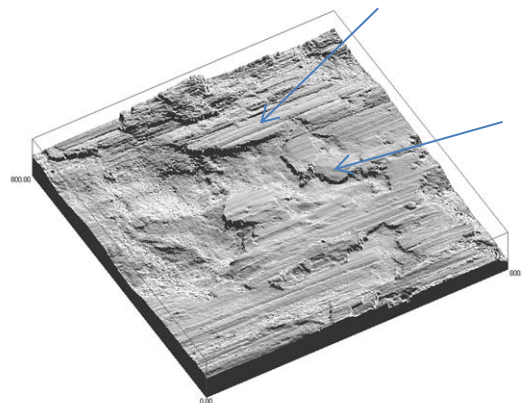


Figure 13 Area E1 from sample D- Shot in photorealistic colour scheme.

Figures 14 and 15 shows plane views area B1 and E1 from sample D- Shot.

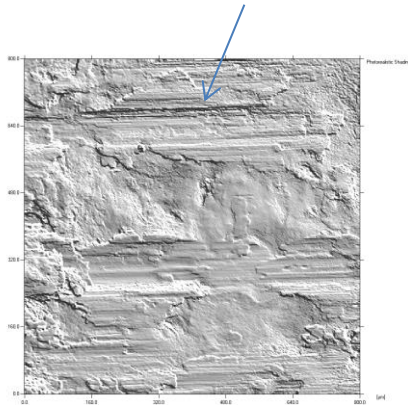


Figure 14 Shows an overview of area B1 from sample D- Shot.

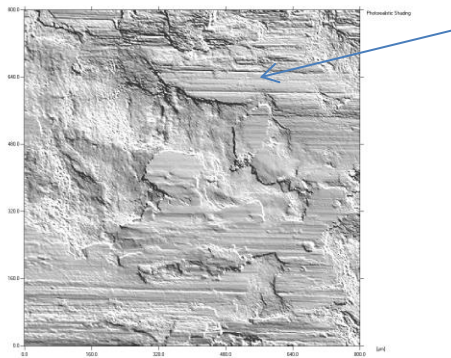


Figure 15 Shows an overview of area E1 from sample D- Shot.

It is quite obvious from Figure 9-15 that the original surface is heavily smeared out in the contact zone and the slip is connected to cold welding areas (arrows) over a large fraction of the surface area.

Figures 16-20 shows areas B1 and E1 from sample D- Grit in both photorealistic and Fire schemes. Figure 18 shows the scale bar for the Fire colour schemes.

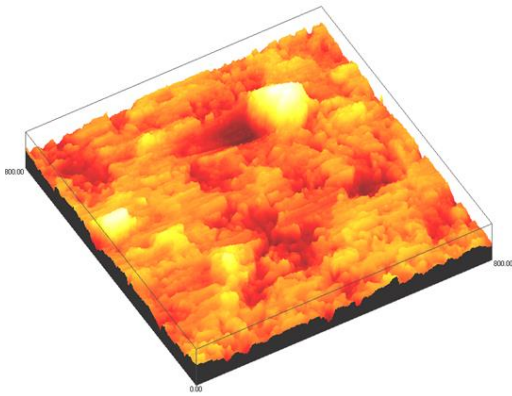


Figure 16 Area B1 from the D- Grit sample in Fire colour scheme. Ra: 5,41

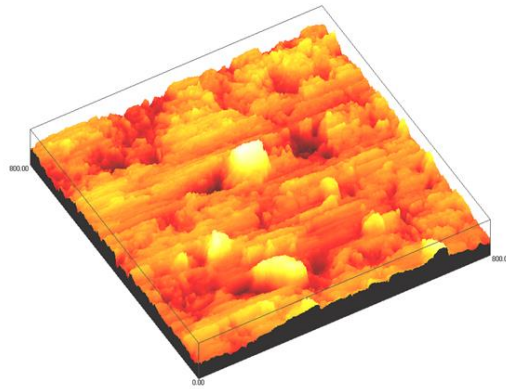


Figure 17 Area E1 from the D- Grit sample in Fire colour scheme. Ra: 5,44

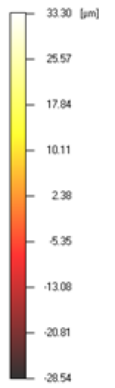


Figure 18

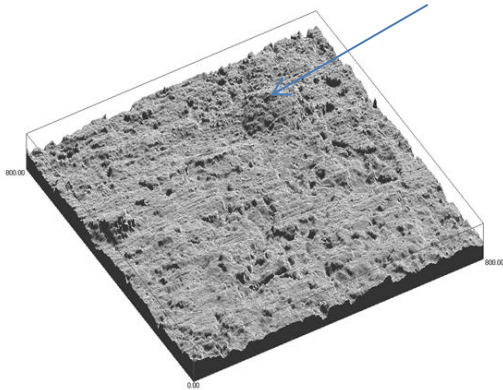


Figure 19 Area B1 from sample D- Grit in photorealistic colour scheme.

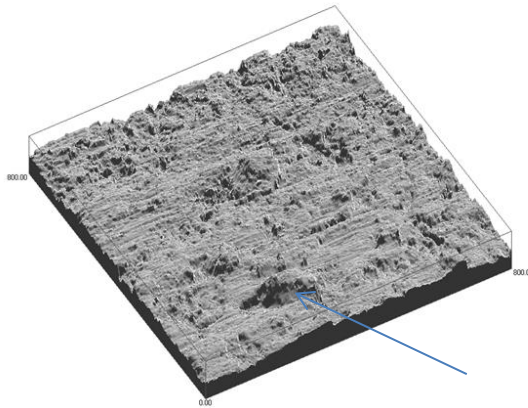


Figure 20 Area E1 from sample D- Grit in photorealistic colour scheme.

Figures 21 and 22 shows plane views area B1 and E1 from sample D- Grit.

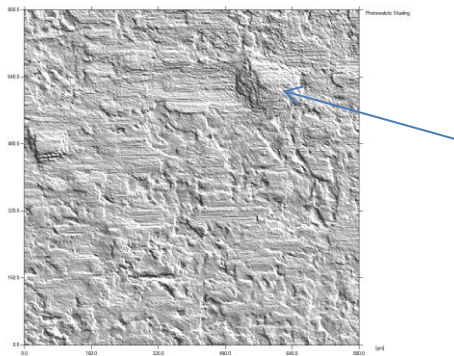


Figure 21 Shows an overview of area B1 from sample D- Grit.

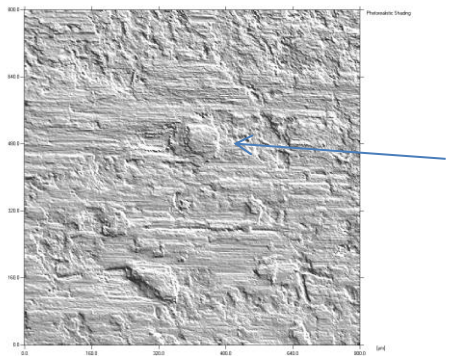


Figure 22 Shows an overview of area E1 from sample D- Grit.

Cold welds can be seen also for D-grit (arrows), but they are smaller and the original sharp asperity appearance is partly preserved, while the D-shot surface seems to be more destroyed by the slip contact.

Figures 23-27 shows areas B1 and E1 from sample A- Grit in both photorealistic and Fire schemes. Figure 25 shows the scale bar for the Fire colour schemes.

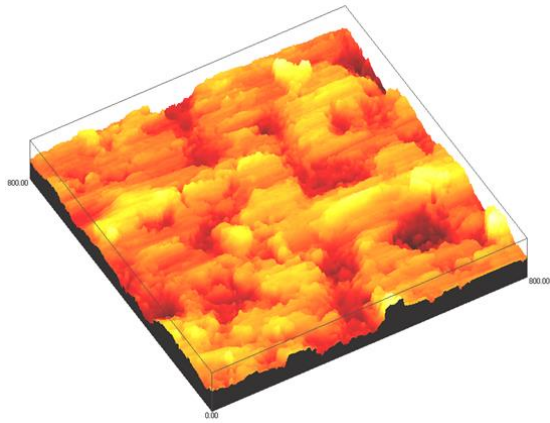


Figure 23 Area B1 from the A- Grit sample in Fire colour scheme. Ra: 8,96

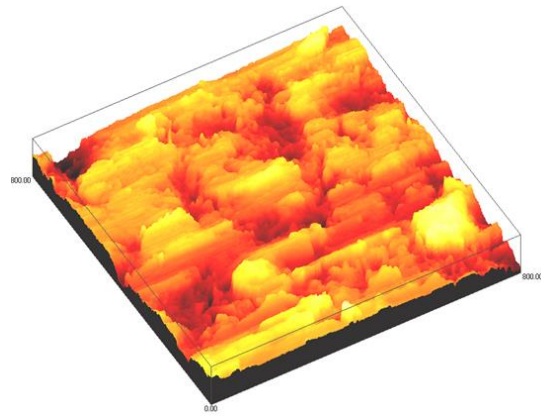


Figure 24 Area E1 from the A- Grit sample in Fire colour scheme. Ra: 7,22

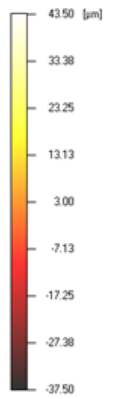


Figure 25

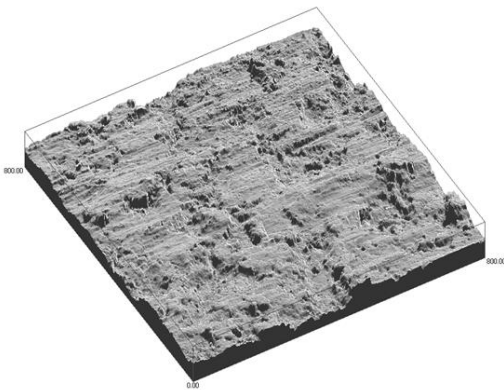


Figure 26 Area B1 from sample A- Grit in photorealistic colour scheme.

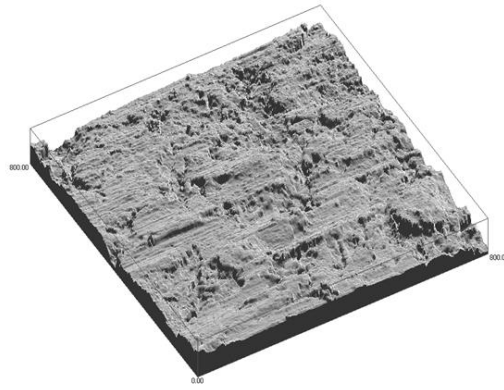


Figure 27 Area E1 from sample A- Grit in photorealistic colour scheme.

Figures 28 and 29 shows plane views area B1 and E1 from sample A- Grit.

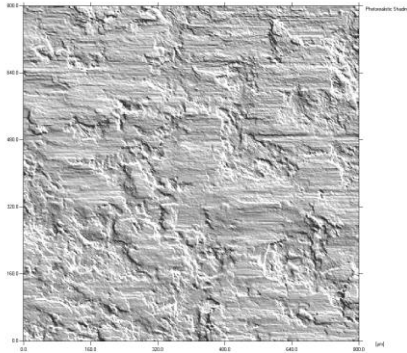


Figure 28 Shows an overview of area B1 from sample A- Grit.

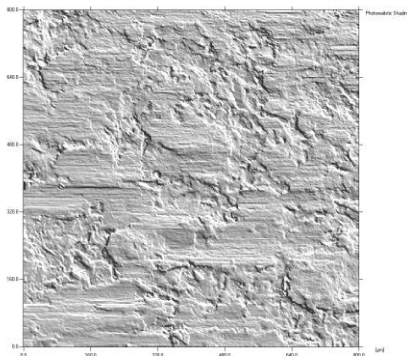


Figure 29 Shows an overview of area E1 from sample A- Grit.

The A-grit sharp surface appearance is more or less smeared out by the slip contact. Cold welds are not as obvious as for the previous tests for D-shot and D-grit.

Table 1 shows Ra- values from the different samples and the examined areas. The contact surfaces (B and E) have a somewhat lower roughness than the original surfaces (A). The decrease is higher for the shot blasted D-shot compared to the grit blasted D-grit. The austenitic surface roughness is higher than the duplex also after slip contact.

Table 1 Ra - Values from the different samples and areas. Ra- value average of five measurements in different areas.

Ra- Values			
Sample	A1	B1	E1
D- Shot	5.37	4.70	4.92
D- Grit	5.44	5.41	5.44
A- Grit	9.37	8.96	7.22

In table 2 the results from surface hardness measurements are shown. The values are averages out of five measurements from different locations on the samples. The results on A- Grit are estimates due to the low scale for the Equotip equipment. The higher hardness of the duplex samples is obvious. No significant hardness increase as a result of the slip contact can be measured. This is probably due to the load level used giving more of bulk hardness than a surface hardness.

Table 2 Surface hardness in HRC from Equotip measurement. Values are averages from five measurements in different areas.

Hardness in HRC			
Sample	A1	B1	E1
D- Shot	25.94	27.24	25.94
D- Grit	28.06	24.72	28.06
A- Grit	19.1	18.8	19.1

5. Discussion

The austenitic grit blasted surface (A- Grit) has a significantly higher roughness than the duplex steels, and a high visual roughness as can be seen from the confocal pictures. From the hardness measurements it is obvious that this is due to the lower hardness of the austenitic surface compared to the duplex. The blasting treatment penetrates easier into the austenitic surface creating a rougher surface. The grit blasted duplex surface roughness is higher than the shot blasted and the surface appearance is “sharper” than the more blunted shot blasted.

The slip resistance seems to be connected heavily with cold welding. These are probably formed as a result of the tightening procedure before the slip test. The coefficients of friction reported in [1] are 0.57 for A-grit, 0.65 for D-grit and 0.35 for D-shot. Based on the appearance of the surfaces before and after the slip factor test it is suggested that the slip resistance is due to a combined effect of cold welding and mechanical interlocking between surface asperities. The higher surface hardness of the duplex compared to the austenitics then explains the higher coefficient of friction of D-grit compared to A-grit since the mechanical interlocking will be more efficient the harder the asperities are. The fact that D-shot has lower coefficient of friction than D-grit is explained by the more blunted surface of D-shot that does not give effective enough mechanical interlocking.

6. Conclusions

- The austenitic A- Grit sample which is Core 304L is softer than the duplex and super duplex samples, which are Forta DX 2205 and Forta SDX 2507. This is demonstrated by the higher Ra-values from the reference area A1, and is also visualised in the examination from the confocal microscope.
- The grit blasted duplex and super duplex grades in sample D- Grit have the lowest surface roughness difference between reference area and contact area.
- The coefficient of friction measured in the slip factor test is suggested to be due to a combination of cold welding and mechanical interlocking of surface asperities.

7. References

1. Task 6.2 indicative slip factor of SS plates, TUDelft presentation, Espoo 16-17 June 2015