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INFLUENCE OF ADHESIVE BONDED SURFACE TEXTURE ON ADHESIVE BONDING PROCESS

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Abstract. Laboratory experiments deal with an influence of a grit-blasting by means of corundum grits AL_2O_3 of different sizes on a surface roughness of steel substrates prepared according to the standard CSN EN 1465.

The experiments considered not only the grain size of a grit-blasted medium (F14, F24, F40, F80 and F100) but also the grit specific size of a main fraction specified by the standard FEPA „F" 42-D-86 which can cause a relief irregularity of the grit-blasted surface, influence the roughness and consequently the adhesive bond strength. Two parameters of the surface texture set by the standard CSN EN ISO 4287 were evaluated: R_a, R_z and their mutual relation R_a/R_z.

The results showed that the percentage of the grit specific size stated by the standard is the lowest at the grain size F80 (56.5% of measured grits) and the highest at the grain size F24 (77% of measured grits). Further, a significant falling course of the roughness parameters values with the increasing grain size of the grit-blasted medium was found out.

The grit-blasting by means of the artificial corundum of the grain size F24 was chosen as the most suitable adhesive bonded steel substrate surface treatment.

Keywords: surface roughness, adhesive bonding, grain size, grit blasting

1. Introduction

A proper treatment of bonded parts surfaces causes an increase of an adhesive strength [16]. Comyn [2] dealt with adhesion theories and with methods of an adherend surface treatment before the adhesive bonding in his paper. He recommends a use of mechanical operations when preparing the metal surface, mainly iron alloys.

The use of chemical cleaning is suitable to reduce if need be, only to degreasing processes which should remove the oil, the grease etc [2].

The aim of the mechanical operations is to reach a certain degree of the adherend surface roughness [17]. The roughness is often used as the model parameter of adhesive bonds and many researchers investigated its effects to the adhesive bond strength and durability by means of different adherends and adhesives [4, 5, 10, 11].

The relationship between the roughness and the adhesion is not simple. The surface optimum profile depends on a type of an applied loading and on an adhesive.

The surface treatment is carried out with the aim to reach the maximum surface wettability by a chosen adhesive. This created ideal conditions for a contact of the adhesive and the adherend surface and consequently a rise of adhesive bindings. The adhesive bonded surface wettability depends on a surface energy and on a surface texture which is represented by the roughness above all [1, 12].

The larger part of adhesive bond surface participates in the adhesive bindings creation and the higher is the number of the adhesive bindings, the higher is the adhesive bond strength [4, 6].

In accordance with this statement is the result of [13] who states that the increase of the surface area can lead to proportional increase of the adhesion at the surfaces with higher roughness parameter values so long until the surface roughness reduces the contact between surfaces [13].

The adherent roughness increases with the adhesive bonded surface mechanical treatment. The surface mechanical treatment raises the adhesive bond area as well thanks to larger efficient surface area for connecting [9].

Hitchcock et. al. [8] and Tamai with Aratanic [18] found out too that the specimens roughening have cause the decrease of their wettability. The simple explanation is that peaks of a long protrusion create barriers which restrict drops spreading.

Two basic principles exert in the adhesive bonded surface mechanical treatment – abrasive and erosive wear. The erosive wear is typical for such cases of the adhesive bonded surface mechanical treatment as grit blasting.

The erosive wear forms by an impact of particles included in a pouring medium to the surface. The uneven surface failure is typical for the erosive wear which is waved and wrinkly [15].

Wang and Yang [19] found out that the material removing at the erosion by the solid particles on the toughing material (figure 1) such as the metal material is caused by the processes of micro-cutting and micro-scraping in which the material demonstrates a huge plastic deformation in the impact point.

From the presented results it eventuates that the plastic deformation at the angle 90° is bigger than the situation at the angle 30°, but the material weight losses are lower at the angle 90° than at the angle 30°.

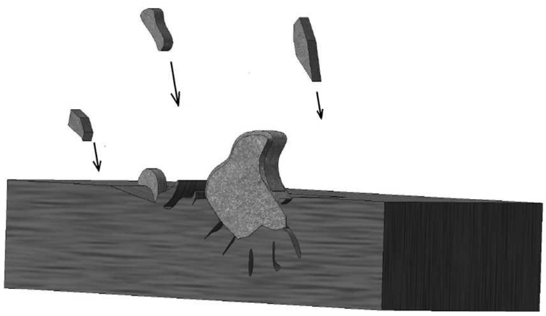

Figure 1. Erosive failure manner of toughing material

Poorna Chandler et al. [14] elicited that the rebuff effect was much more penetrative and the indented surface roughness tended to be higher with the increasing impact angle.

The hardness HV 10 was higher at the surface grit blasted at the angle 90° than at different angles until the 90°.

Harris et al. [7] learned in their works that slight differences in the types of grit blasted grains present measured parts in the surface characterisation. Raw texture measurements confirmed their expectations that rougher grit created rougher surface and generally rougher surfaces display lower surface energies. Authors [14] state the same conclusions.

Authors [18] found out that despite the grit blasting leaded to higher adhesive bonds strength compared with other mechanical procedures of adherent surface treatment there is no difference in the adhesive bond strength when grit blasting with slight and rough grains.

2. Methodology

Experiments focused on the adhesive bonded surface treatment by the grit blasting deal with the appraisal of the influence of the grit blasted corundum grain different size on the steel substrate surface roughness and with the leverage to the adhesive bonds strength characterizations. The grit blasting belongs to the most used surface treatment manners before the adhesive bonding application.

When evaluating the experiments, it is necessary to consider not only the grit blasted medium graininess, but also main fraction specific grain dimension, which is specified by the standard FEPA "F" 42-D-86. The prospective grains dimension fluctuation can cause an irregularity of the grit blasted surface relief which will influence the surface roughness and also the adhesive bond strength at the end.

The laboratory experiments were carried out on the standard test specimens made according to the standard CSN EN 1465 from non-alloyed constructional steel S235J0 with ferrite microstructure with the tertiary cementite.

The test specimen surface was mechanically treated by grit blasting with the artificial corundum (Al_2O_3) of granularity 14, 24, 40, 80 and 100 before the adhesive bonding. The area grit blasting was carried out by the pressure 4 000 kPa.The jet and the specimen gradient was 90° in the constant distance 100 mm. The grain dimension of particular granularities was verified by means of the picture analysis carried out with the stereoscopic microscope attached with the digital camera Artcam – 300 MI.

Two texture surface (roughness) parameters R_a and R_z defined by the profile method specified in the standard CSN EN ISO 4287 were evaluated at the mechanically treated areas. Also the ratio of above mentioned parameters (R_a/R_z) stating the proportion of average and the highest peaks of the profile inequality was used for the surface roughness evaluation. Prospective positive and negative deviations from the surface uniformity can influence the adhesive bond strength. Higher value of this proportion secures the elimination of deviations from the mean R_a.

Specimens were cleaned by the ultrasound in the perchlorethylen bath before the roughness measuring. The surface roughness parameters were measured by the contact profilemeter Surftest 301. The marginal wave length (cut-off) was set as 0.8 mm. The adhesive bond strength itself was measured by means of the destructive testing in the cutting machine.

The adhesive bonding process itself was carried out on the glass plates. The test specimens were prepared according to the standard CSN EN 1465 by pasting two materials of dimensions 100 ± 0.25 x 25 ± 0.25 x 1.6 ± 0.1 mm so that the recommended overlapping length was 12.5 ± 0.25 mm [3].

The two-component epoxy adhesive Bison epoxy metal was used for experiments. The adhesive layer was put on one piece of the specimen so that the whole surface was regularly covered within the marked area (12.5 mm). Two distance wires of required mean were put into this layer. The distance wires were put parallel to the loading direction when testing shear strength.

Then the second piece of specimen (steel plate) was applied. This piece of specimen was applied in that way so that the overlapping 12.5 mm could be reached [3].

The upper applied specimen was supported by the plate of the same thickness (1.5 mm) and the specimens were aligned in the lengthwise axis. The specimen set was loaded down by a weight of 720 g immediately after this.

The created bond was left in the laboratory at the temperature 23 ± 2 °C for the time interval stated in the adhesive manual to reach the hardening.

3. Results

An important factor influencing roughness parameters is the grain dimension. This information is stated in the interval of values representing the sedimentation curve fifty percentage point of evaluated grain.

Measured value results of relevant grain dimension were put together in the form of box diagram, such as figure 2.

When evaluating carried out experiments with the grain dimension of relevant graininess stated by the standard, it was found out following:

- 59.5% of measured grains fulfilled the specific grain size stated by the standard for the graininess F 14 in the interval 1400 – 1700 µm.

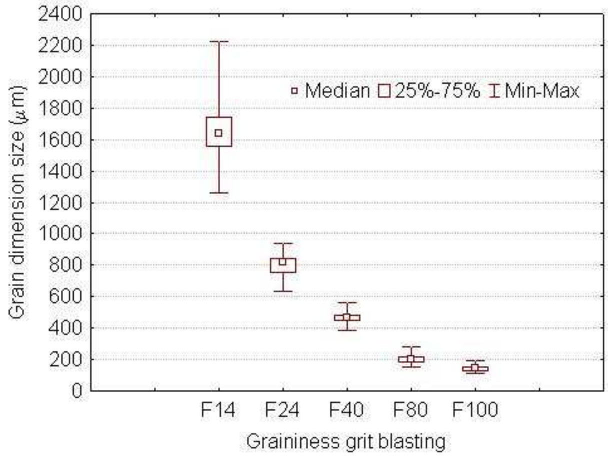

Figure 2. Box diagram

- 77% of measured grains fulfilled the specific grain size stated by the standard for the graininess F 24 in the interval 710 - 850 µm.
- 75.5% of measured grains fulfilled the specific grain size stated by the standard for the graininess F 40 in the interval 425 - 500 µm.
- 56.5% of measured grains fulfilled the specific grain size stated by the standard for the graininess F 80 in the interval 180 - 212 µm.
- 64% of measured grains fulfilled the specific grain size stated by the standard for the graininess F 100 in the interval 125 - 150 µm.

Above presented results correspond with the average size of the grain basic fraction representing the sedimentation curve fifty percentage point of evaluated grain.

The dependence of roughness parameters (R_a, R_z) change on the different graininess of the grit blasted material was observed at the grit blasted surface. The significant influence of grit blasted grains different sizes affecting the erosive wear of the steel S235JO showing the decreasing trend can be seen from the measured results presented in the figure 3.

The dependence course (figure 3) is described by the power function which corresponds to the correlation fields the best. Functions stated in the figure 3 are described by following equations (1, 2) and they denote the dependence of roughness parameters (R_a, R_z) on the grit blasted artificial corundum graininess (F).

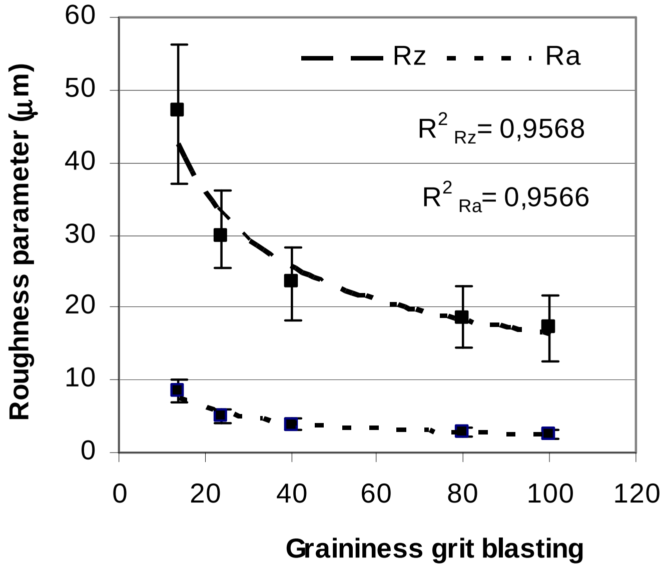

Figure 3. Influence of grit blasted artificial corundum graininess on roughness parameters

$$R_a = 152.9F^{-0.4846} \quad (1)$$

$$R_z = 33.684F^{-0.5658} \quad (2)$$

In the figure 4 it can be seen the gradual linear increase of roughness parameters values when comparing different grit blasted grain sizes of relevant fractions. Measured values of the grain dimension fulfilled the assumption corresponding to the fiftypercentage sedimentation point. The roughness parameters (R_a, R_z) increased linearly with increasing grit blasted grain size. This trend occurred also at minimum differences in grain sizes. Author [7] came to the same conclusion.

Function equations (3, 4 and 5) describe the roughness parameters (R_a, R_z) dependence on the grit blasted artificial corundum grain size (x) – figure 3.

$$R_a = 0.0039x + 2.0347 \quad (3)$$

$$R_z = 0.0197x + 14.448 \quad (4)$$

$$\frac{R_a}{R_z} = 2 \cdot 10^{-5} x + 0.152 \quad (5)$$

The ratio R_a/R_z ranged in the interval 0.15 ± 0.01 – 0.18 ± 0.01. The higher ratio (32.5%) of grains up to the extent corresponding to the fifty percentage sedimentation point was interpreted on the base of the picture analysis at the graininess F 14. The higher ratio of mentioned grains ranged from 13 to 24% at the other types of graininess. From this, we can assume higher value of the R_z parameter indicating the local occurrence of increasing values of the highest and the lowest profile peaks. The average value of the ratio R_a/R_z for the artificial corundum grit blasting method was calculated as 0.164 ± 0.01.

The dependence of the adhesive bond strength change on the surface mechanical treatment by grit blasting of various types of graininess simultaneously with noting the influence of adhesive layer thickness is stated beneath. The grit blasting by artificial corundum of the graininess F 24 and the adhesive layer thickness 0.125 was evaluated as the optimum from the measured values.

When processing the results by means of the 3D contour line graph (figure 5) created by the lowest squares method in the programme STAT SOFT Statistika it was ascertained wider belt of the graininess optimal values and the adhesive layer thickness for particular adhesives. As the optimum treatment it was found out from the graph the artificial corundum grit blasting in the interval of graininess F 20 – F 24. The trend of strength decreasing can be seen from the figure 5 when applying the erosive grains with higher or vice versa smaller dimension. This trend is supported by the conclusions reported by authors [8] and [18].

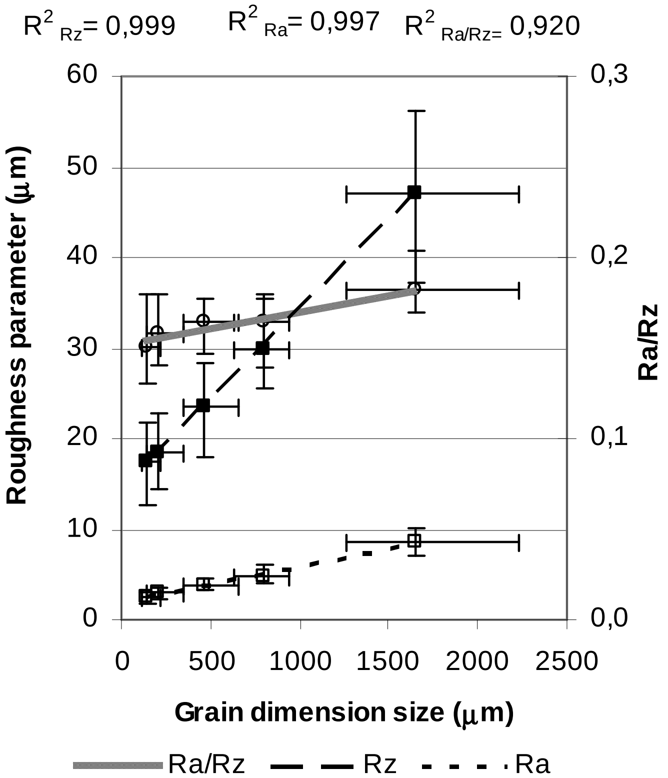

Figure 4. Influence of grit blasted artificial corundum grain size on roughness parameters

Installing found out values to the functional equations (1) and (2) it was calculated presumptive values of the roughness parameters R_a 6.18 – 5.58 µm and R_z 35.80 – 32.78 µm. The adhesive layer thicknesses were in the interval 0.115 – 0.165 mm. Not only the influence of different adhesive surface mechanical treatment, but also of the adhesive layer thickness can be seen from the adhesive bond strength results showed in the figure 5. The strength decrease between the optimum and the unsuitable adhesive surface treatment was in average 38.11%. This fact oppugns the theory of author [7] who declares that it is not reached more significant difference of the adhesive bond strength when grit blasting by various grain sizes. The difference between the optimum and the unsuitable adhesive layer thickness was 10.49% in average.

The failure area was evaluated as the cohesive type (CF) at all destructed adhesive bonds whose adhesive surface had been treated by the artificial corundum grit blasting of the graininess F 14 – F 80. The failure area was of the special cohesive type (SCF) at the destructed adhesive bonds whose adhesive surface had been mechanically treated by the artificial corundum grit blasting of the graininess F 100.

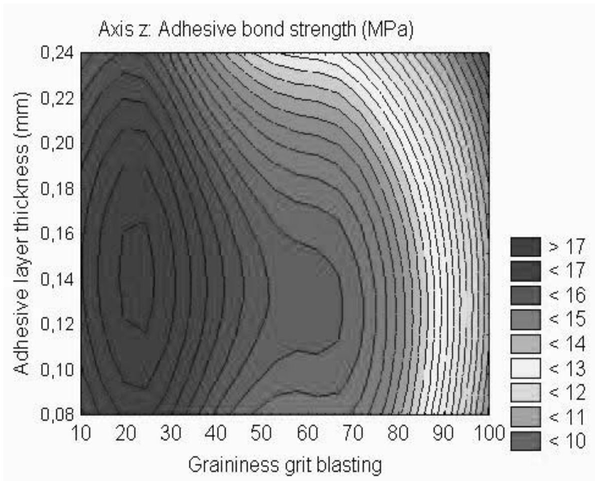

Figure 5. Influence of grit blasted artificial corundum graininess and of adhesive layer thickness on adhesive bond strength – 3 D contour graph (method of least squares)

4. Conclusion

We can conclude from the experiments in accordance with the literary background that it is not possible to set only the necessity to carrying out the mechanical treatment, but also it is necessary to set the exact adhesive surface treatment. The use of unsuitably chosen abrasives pertinently in the combination with unsuitably chosen adhesive layer thickness can cause significant adhesive bond strength decrease. When comparing the optimum mechanical treatment and adhesive layer thickness with completely unsuitable conditions the adhesive bond strength decreased to 38.40%. This percentage quantification of single factors specifies clearly the indispensability together with the importance of securing the optimum factors for adhesive bonding application.

A few important steps which are necessary for proper evaluation are sum up from the experiences gained during the experiments:

- First presumption is the basic information about the connected materials. Before the beginning of the exact adhesive surface mechanical treatment the material type has to be determined.
- Second step is to apply a suitable grit blasting medium. Using the grit blasting material (in this case Al_2O_3) of the graininess F 24 with the average grains dimension of 788 µm seemed to be the optimum in experiments carried out on the steel S235JO. However, the necessity to set the optimum graininess for other types of material was found out on the base of former researches.
- The last essential step is the adhesive bond creation itself in which the adhesive layer, the fixation and the hardening conditions are important. Mainly the adhesive layer thickness is important not only because of the strength characteristics, but also because of prospective adhesive bond creation costs.

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