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Analysis of Water Pollution Indicators with the Use of Selected Statistical Methods

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KEY WORDS
Adhesive bonding, surface pretreatment, stainless steel, shear strength.

ABSTRACT
This article presents the problem of joining stainless steel which is used to produce various construction elements which are exposed to chemically active substances. Some traditional methods of joining sometimes are not possible to be put into use. The constructions cited here are frequently welded, however, investigated steel is not resistant to brittle failure after welding, thus it is not recommended for welding process. Adhesive bonding is suggested here as an effective method of joining elements of this material. Different methods of surface pretreatment were analysed before bonding with the use of several adhesives. Joints were tested for static strength. The results of experiments and conclusions are presented in this paper.

1. Stainless Steel Properties

WStainless steels are highly-alloyed and are used only in particular cases because of their high cost. Nevertheless, they characterise of specific properties: high hardness, resistance to abrasion. This properties are optimal under condition that the structure of steal will not change during e.g. technological operations connected with heating or material melting. Steels containing 10,5-30% chrome are sensible to overheating, characterize of low carbonic content, do not harden and have fines structure. Brittleness increases due to overheating. This process is irreversible, thus the limited weldability of chrome ferritic steals which tested in the experiment X6Cr17 steel belongs to. On account of the formation of martensit in transition zone or relatively ferrit glutted with carbon or nitrogen, during the welding of this steel in order to obtain seams without cracks, it is necessary to apply certain thermic procedures. This procedures characterise of cindering the joints in the temperature of about 300°C, during which nitrogen and carbon that are located in the glutted solution, diffuse along grain boundaries, form carbonitrides and thereby improve plasticity of ferritic grains and the whole joint [5]. Tab.1 presents steal composition and tab.2 its properties.

This steel belongs to steel group applied in many branches of industry – rafinery, petro chemistry, for tanks and installations in chemistry industry, shipbuilding industry, in aircraft manufacture. Steels in these branches can be used without protection shields (painting, galvanizing) [2], [6].

2. Adhesive Bonding Practicability

Adhesion and cohesion, wettability

In case of joining elements of a small size, complex shapes, difficult to be joined with other methods, with the limited access and free space of the place to use tools, an adhesive bonding may be applied.

It is a multi advantage technology that allows to:

- *join together different materials,*
- *avoid electrochemical corrosion,*
- *obtain positive stress distribution,*
- *lower the construction weight,*
- *use widely available and cheap adhesives [4].*

Table 1: *Chemical composition of X6Cr17 [7]*

Element	Mass fraction	Element	Mass fraction
C	≤0,08	W	-
Mn	≤1,00	V	-
Si	≤1,00	Co	-
P	≤0,04	Cu	-
S	≤0,015	N	-
Cr	16,0-18,0	Ti	-
Ni	-	Al	-
Mo	-		-

Table 2: *Mechanical properties of X6Cr17 [7]*

Property	Value
Tensile strength, R[MPa]	400-630
Yield strength Rp0,2 [MPa]	≥240
Strain, A [%]	≥20
Hardness, HB [HB]	≤200
Elastic modulus, E [GPa]	220

The condition of obtaining a durable joints is a good adhesion, so the grip to the laminated surfaces and cohesion - integrity of laminated substance. Adhesion forces depend on the surface properties, its shape and development, the chemical constitution of the surface and the adhesive. Thus the adhesion can be divided into mechanical adhesion and actual adhesion. The mechanical adhesion is determined by the refusal of adhesive mass which is located in interspaces of joining elements. The strength of seams is increased when the adhesive surfaces have developed surface (e.g. obtained through roughening). Than, the adhesive mass penetrates hollows and places inside and cause that the surface where the adhesive contacts with the base, is bigger than in a geometric perspective. The actual adhesion is conditioned by affecting of the attraction forces between the adhesive and the joining surface. This adhesion is the result of chemical forces in bonds, physical and chemical absorption, molecular and electrostatic fixations and van der Waals forces.

Wettability plays the crucial role in the joint strength. It depends on the wettability angle θ which should have a low value (Fig.1).

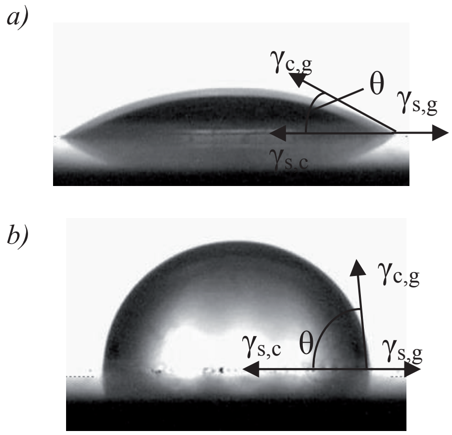

Fig. 1: *Formulaic repesentation of proper a) and improper b) wettability (on the basis of [3]).*

The problem arises with the application of adhesive: liquid adhesive applied on the solid body in the air means contact of boundaries of three phases, as a result of it: three limiting surface tensions $\gamma_{s,c}$, $\gamma_{c,g}$ and $\gamma_{s,g}$. Wettability angle depends on the value of surface tension on the border of phases solid body-gas $\gamma_{s,g}$ and solid body -liquid $\gamma_{s,c}$:

$$\cos\theta = \frac{\gamma_{s,g} - \gamma_{s,c}}{\gamma_{s,g}} \qquad (1)$$

A good wettability takes place when the surface tension on the border of phases solid body-liquid and liquid-gas is low in comparison to the surface tension on the border of solid body-gas. In practice, the situation can be improved by purification, especially degreasing [8].

Surface pretreatment before adhesion

The surface pretreatment stage before creating joint has a critical role in terms of the effects. The configuration of a particular condition of surface layer can be conducted through many methods depending on the combining materials. In case of metals, the first step is to purify the surface from dirt - grease, oils, silicon, oxide, from paints or glue from previous processes. After cleaning, the adhesion abilities increase, skipping this phase leads to the decrease in the joint strength.

The properly prepared surface characterizes of:

- *the lack of pollutants that reduce adhesion;*
- *good adhesive wettability;*
- *the ability to create interfacial fixations;*
- *the stability of assumed conditions and extraction time of joint;*
- *repeatability of obtained properties;*
- *the presence of activators, if needed.*

The next stage of surface pretreatment is its development and activation. This stage mostly is conducted through mechanical treatment, changes surface topography and its reactivity. This treatment is implemented through grinding, shot blasting, roughening etc. These procedures increases the contact surface of adhesive and the base, the material adhesion increases. (Sometimes unconventional methods might be used - heater treatment, UV rays, plasm). The mechanical treatment itself cannot provide a good activation of the surface in spite of its maximal development configuration. Thus the next stage is chemical treatment - digestion in acid solution, oxidation, anodising. Apart from removing pollutants, they reduce the thickness of oxides layer. Sometimes the surface prepared in this way can be layered with primer, adhesion activator, that react with both the surface and the adhesive simultaneously [1].

3. Desription of Experiment

Preparation of samples

The samples used in this experiment are of size: 25±0,5x100±0,5 and thickness 1 mm of steel X6Cr17. Single-lap joint, lap 12,5 mm with 5-time repetition of experiment.

Adhesives used:

- *two-component epoxy Araldit 2014-1 - overlaid on both bonding surfaces,*
- *one-component metacrylic with hardener in form of lacquer Agomet (Araldit) F300 - lacquer overlaid with one of the bonding surfaces, the adhesive on the second.*

The surfaces were pretreated in the manner as follows:

Variant 1: purified with acetone, dried without roughening.

Variant 2: purified with aceton, dried, abrasive paper with the grain P80, rinsed in ultrasound wash, dried.

Variant 3: purified with aceton, sandblasted with corundum 95A with the grain number 60, rinsed in ultrasound wash, dried.

Drying, adhesion, hardening of the adhesive were performed in temperature about 24°C, with the same load.

Results of wettability measurement

On the separate (but prepared in the same manner) samples of the size of 15±0,2 x 50 x 1 [mm] wettability measurement were taken with FIBRO goniometer PG-3 (Fig. 2).

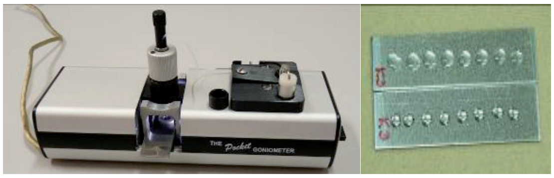

Fig. 2: *Wettability measurement with goniometer PG-3:a) measuring, b) drops of water and diiodomethane.*

Direct measurement of angle is the basis for calculation of surface free energy with Owens-Wendt method. In this method the surface energy has two component parts: dispersive and polar. Free energy algorithm is:

$$\gamma_{s,g} = \gamma_{s,c} + \gamma_{c,g} \cos\theta \qquad (2)$$

The measurement is taken by two measuring liquids - water and diiodomethane - with known energy values and next set components of free energy of analysed material (Tab.3). The results are presented in Tab. 3.

Results of static strength measurement

The static strength of joint was tested after adhesion with the use of strength machine INSTRON 3382. The measurement was repeated five times for the each variation. The results are presented in Tab. 4.

Table 3: *Wettability measurements of surface, results.*

Variant	SFE	γp	γd	θw	θd
1	58,8	17,3	41,6	60,4	36,9
2	54,8	12,7	42,1	69,7	35,6
3	60,1	11,58	48,6	69,9	17,1

SFE – surface free energy [mJ/m^2]
γp – polar part
γd – dispersive part
θw – angle of wettability for water
θd – angle of wettability for diiodomethane

Table 4: *The results of joints static strength*

Variant	Epoxy glue		Metacrylic glue	
	$P_{t\text{-}śr}$	R_t	$P_{t\text{-}śr}$	R_t
1	3898,36	12,47	3778,10	12,08
2	5977,82	19,13	5268,76	16,86
3	7071,24	22,62	5595,92	17,91

$P_{t\text{-}śr}$ – mean force to destroy [N]
R_t – static strength of joint with realtion to lap area: Rt = $P_{t\text{-}śr}/A_0$ [n/mm2]; A_0 = 312,5 [mm^2]

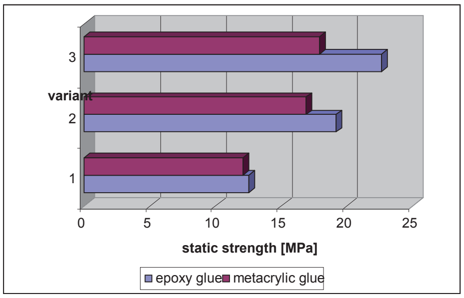

Fig. 3: *Graphical presentation of results.*

4. Discussion of Achieved Results

The measurements of wettability angle and assigning surface free energy, gave the following information:

- *the lowest energy value was obtained for the abrasive paper roughening, the highest for electrocorundum mechanical treatment;*
- *wettability angle with the measure of the water use was the largest and with the use of diiodomethane was the smallest for the sand-blasted surface.*

Gluing surfaces activated in this way brought the following results:

- *the highest static strength to abrasion was obtained for the sand-blasted surface, glued with both methacrylic adhesive (17,91 MPa) and epoxy adhesive (22,62 MPa);*
- *the values of maximal brake force were differentiated due to kind of adhesive.*

5. Conclusion

The obtained results can lead to conclusions that:

- *the choice of the adhesive for particular materials is crucial, a methacrylic adhesive occured to be worst than epoxy adhesive in the experiment;*
- *gluing with epoxy adhesive, despite being more demanding (requires proper adhesive dosage and mixing and hardener) is more effective, in case of liable construction, the joints strength plays the key role;*
- *methacrylic adhesive, even easier while gluing process - the adhesive was applied only on one surface, the lacquer on the second (according to manufacturer guidelines) allows to obtained not so satisfactory results;*
- *in case of quick repairs, gluing with one-component adhesive (with short time of hardening like AGOMET 300) causes less problems, but the final effect of the process should be keep in mind;*
- *the obtained results should be refered to the used material and adhesive types;*
- *gluing is good method to joint unweldable materials.*

6. Acknowledge

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