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MECHANICAL FEATURES OF SYMTHETIC GLUE BONDING OF METALS WITH CERAMIC GLASS

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Abstract: *Adhesive bonding using synthetic materials has gained a wide field of use in the last decade, at bonding metal sheets or metal parts, non-metallic or combined, especially in light construction and precision mechanics, but also in vehicle manufacturing. Instead of metal layer or soldering alloy, a thin layer of adhesive is used, which after application tightens and takes external forces through the mechanical strength due to its mass cohesion and adhesion between the adhesive and the surfaces to be joined. Adhesive bonding is a process with broad application worldwide. In many cases it replaces the classic combination (welding, riveting) and allows bonding of materials with different structures, as in the case studied (metal with glass). According to the mechanical theory connection bonding between the bearing surface and adhesive (or any coating, paint) are made by adhesive infiltration into the pores, asperities (roughness) of the bearing surface. However, this theory can not be generalized because a strong glued joint can be made in the case of smooth material (for example: glass, semiconductor silicon plates). A relatively new scientific branch deals with theoretical basis of the soldering technique, surface engineering(surface engineering, surface science).*

Keywords: *surface engineering, roughness, bonding technology, mechanical connection, strength, metal-glass bonding.*

1. INTRODUCTION

In order to obtain a good adhesion it is necessary to study the basic material and the adhesive which connects to. [5]

Adhesive bonding is a process with wide application in technology. As a related field to welding, in standardization, there are interesting, especially, the requirements regarding preparation of surfaces to be merged, and attempts of adhesive bonded joints. Bonding forces (adhesion and cohesion) have an important role to get a correct joint and to meet requirements (tensile strength, shear strength and detachment, etc. . .).

There are four state standards in force in this field. First, STAS 10535-79, corrlated to ST CAER 138-81 and replaced SR ISO 15787:2008, sets the rules of representation and notes on drawing of bonded joints obtained.

The other three refer to mechanical attempts of adhesive bonding joints and correlated with corespondent standards DIN:

- STAS 12310/1-85, which establishes the conditions for sample preparation and surface to be bonded and test tubes sampling of adhesive bonded joints, for shear tests, tensile, peel (peel) and wear;
- STAS 12310/2-85, which establishes technical requirements for execution of shear test specimens taken from adhesive bonded joints, of the overlapping sheets.
- STAS 12310/3-85, which sets the technical conditions to perform attempts of tensile of specimens taken from head to head adhesive joints. [7]

2. MATERIALS FOR TEST TUBES

Two types of metal can be used to make up test tubes:

- Stainless Steel Sheet - 304-2B ASTM, (X5CrNi18-10), numeric symbol 1.430[2]
  Chemical composition: C_{max} - 0,07%; Si_{max} 1 %; Mn_{max} 2 %; Cr 17-19 %; Ni 8-11 %; P_{max} 0,045 %; S_{max} 0,015 %.
  Mechanical features (Fig.1.):Tensile breaking strength: R_m = 520Mpa; Flow strength, flow limit: $R_{p\ 0,2}$ = 205MPa.; Elongation: A = 40%.

304-2B ASTM steel, (X5CrNi18-10), is the type of austenitic stainless chromium-nickel most used. Its most important property: ductility (elongation) and hard, cold workability and easy punching. The content of at least 7% Ni makes the structure to become fully austenitic, which provides "non-magnetic" properties and a very good weldability. It is widely used in manufacture of household appliances, pipelines and industrial tanks, industrial constructions.

2B (DIN 17441) - represents finished surface most often encountered to ensure corrosion resistance and evenness, having roughness of R_a= 0,10 - 0,30 µm and reflectivity max. 40 % (Fig.2. a and b).

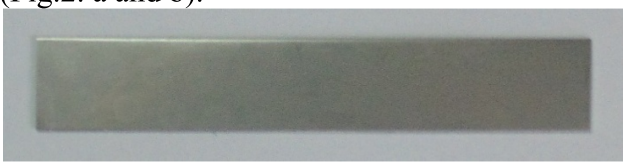


Fig. 1. Stainless steel test tube - size 150x25x1 mm.

a.)

b.)

Fig. 2. a and b) Measurement of uncovered surface roughness.

- Metal sheet - DC 04 EK-M - EN 10209, numeric symbol1.0392 [2]
  Chemical composition: C_{max} - 0,08%;
  Mn_{max} - 0,5%;
  P_{max} - 0,03%;
  S_{max} - 0,05%.
  Mechanical features (Fig.3.):

Tensile breaking strength: R_m = 270-350 MPa.

Flow strength, flow limit: $R_{p\ 0,2}$ = 220MPa.

Elongation: A = 38 %.

DC 04 EK steel is type of steel which allows slight processing at deep drawing and offers a good wear at enamelling processes (wet or dry). DC 04 EK steel is widely used in the manufacture of household appliances, sanitary ware, architectural panels.

M - reprezintă laminare termomecanică (rulare), suprafața având rugozitate is thermomechanical lamination (rolling), with surface roughness of R_a = 0,60 - 1,90 µm (Fig.4. a and b).

After obtaining the metalic support, a protector paint layer is applied in electrostatic field.

Fig. 3. Steel test tube, painted in eletrostatic field - size 150x25x1 mm.

a.)

b.)

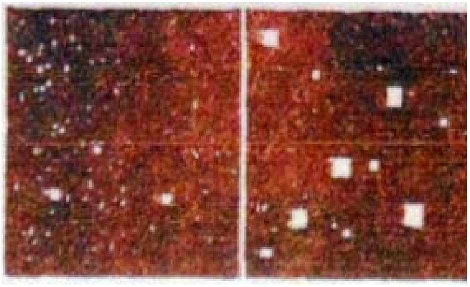
Fig. 4. a and b) Measurement of covered surface roughness, painted in electrostatic field.

- Glass ceramic - is a polycrystalline material by controlled crystallizing of the basic glass.

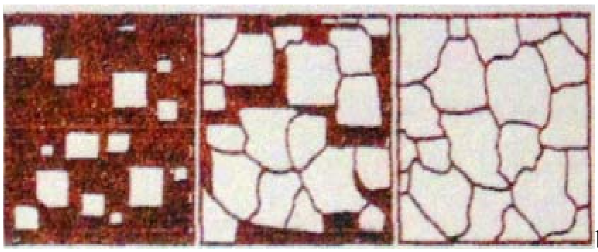
Glass ceramic has an amorphous phase and one or more crystalline phases produced by a so-called "controlled crystallization" (Fig.5. a and b), in contrast to a spontaneous crystallization, which is usually is not desired in the glassmaking. Glass ceramic has the advantage of glass manufacturing, as well as the special properties of the ceramics.

All thermic properties of glass are important for the technology, due to the fact that during its production, the glass is heated, melted, cooled, thermally treated in a very wide range of temperatures (Fig.6.).

In this thermic treatment glass is crystallized, at base composition of glass "heterogeneous germs" are added - solid particles of other nature, in general ceramics, these germs help and control the process of crystallization.



a.



b.

Fig. 5. The process of crystallization
a. - Germination, b. – Germs growth and formation of structure. [3]

Mechanical features (Fig.7.):

Tensile breaking strength (tear):

$$R_m = \frac{F_{max}}{A_0} = 100 - 250\ MPa \quad (1)$$

Longitudinal elongation module (Young's module): [8]

$$E = \frac{\sigma}{\epsilon} = 120\ GPa = 120.000\ MPa \quad (2)$$

Density:

$$\rho = 3\ g/cm^3 \quad (3)$$

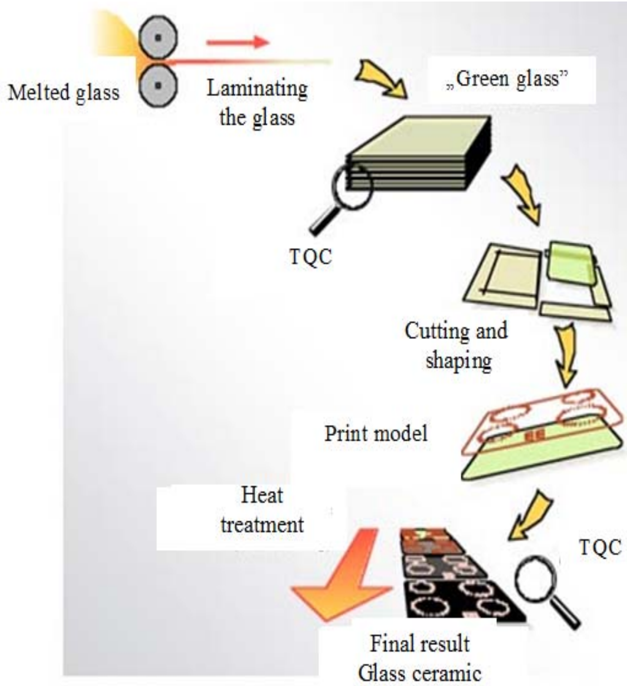


Fig. 6. Stages for obtaining glass ceramic.[10]

Fig. 7. Glass ceramic, EUROKERA,size 150x25x4 mm.

- One component adhesive silicone S95 CO4 (Fig.8.):

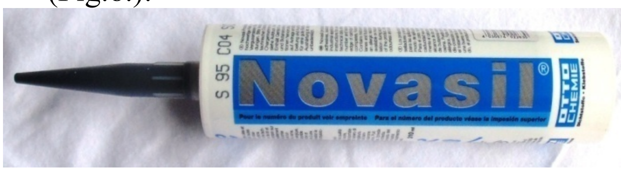


Fig. 8. One component adhesive silicone S95 CO4.

This adhesive was conceived especially for bonding glass ceramic while ensuring elasticity and tightness. The adhesive silicone is in the form of paste having a stable viscosity. [11]

3. SURFACES CONDITION

Surfaces condition of a piece is defined by characteristics that express the geometric and physico-chemical state thereof.

Surface roughness is made up of microirregularities of actual surface that influence the contact of surfaces with adhesive for bonding.

After surface measurement the following values were obtained:

$$R_{a\,med} = 0{,}09\ \mu m \text{ - stainless steel surfaces} \quad (4)$$

$$R_{a\,med} = 0{,}28\ \mu m \text{ - painted surfaces} \quad (5)$$

Average arithmetic deviation of the profile, R_a - average arithmetic of absolute values of profile deviation, within limits of basis length (Fig.9.).

Average arithmetic deviation is calculated:

$$R_a = \frac{1}{l}\int_0^l |y(x)| \cdot dx \quad (6)$$

or aproximately:

$$R_a \approx \frac{1}{n}\sum_{i=1}^{n} |y_i| \quad (7)$$

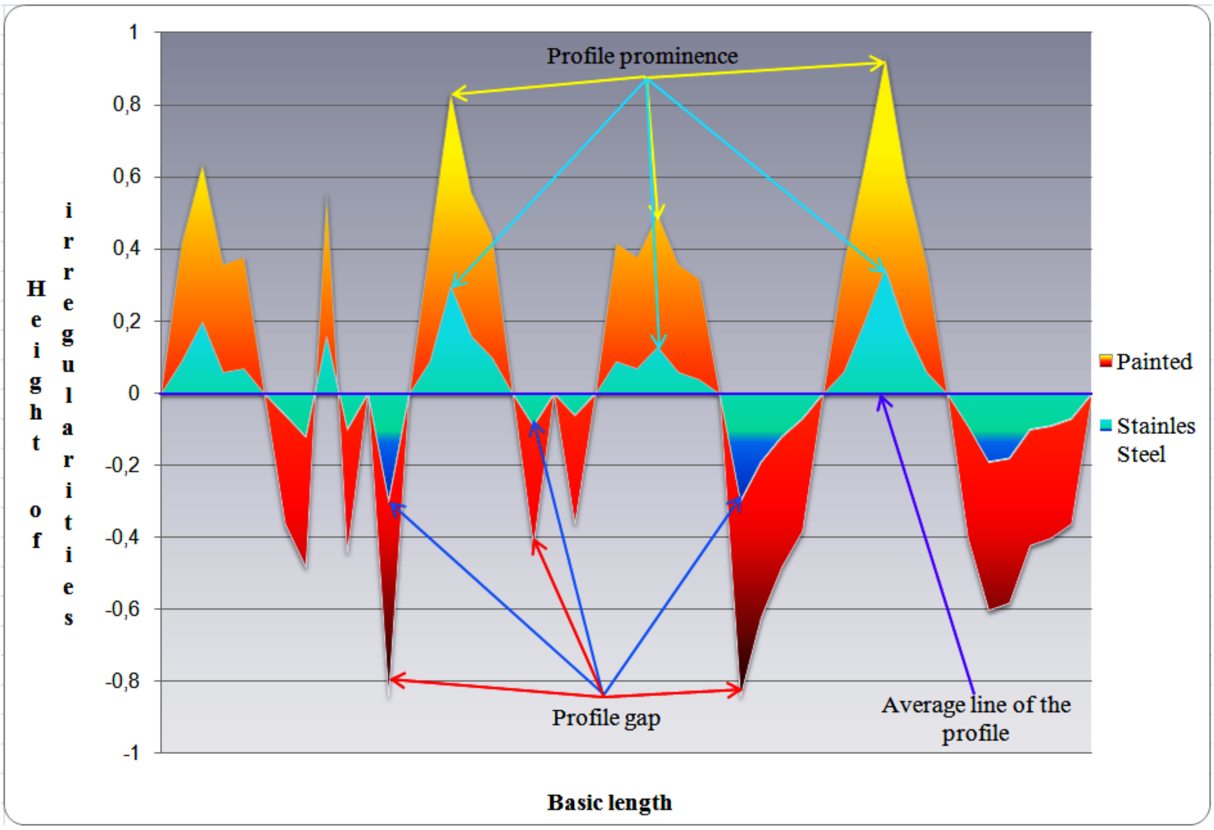


Fig. 9. Theoretic representation of studied surfaces.

- The projection profile is the profile oriented to exterior material and hold between two consecutive intersections of profile with the average line.
- The gap of profile is that side facing the interior of the piece material and between two consecutive intersections of profile with average line.
- Basic length is the length of the reference line, which is used for the separation of irregularities that make up the surface roughness . [4]

Considering relations (6 and 7), where height values of irregularities are in the module, thus having positive values, we present the measured values (Fig.10.).

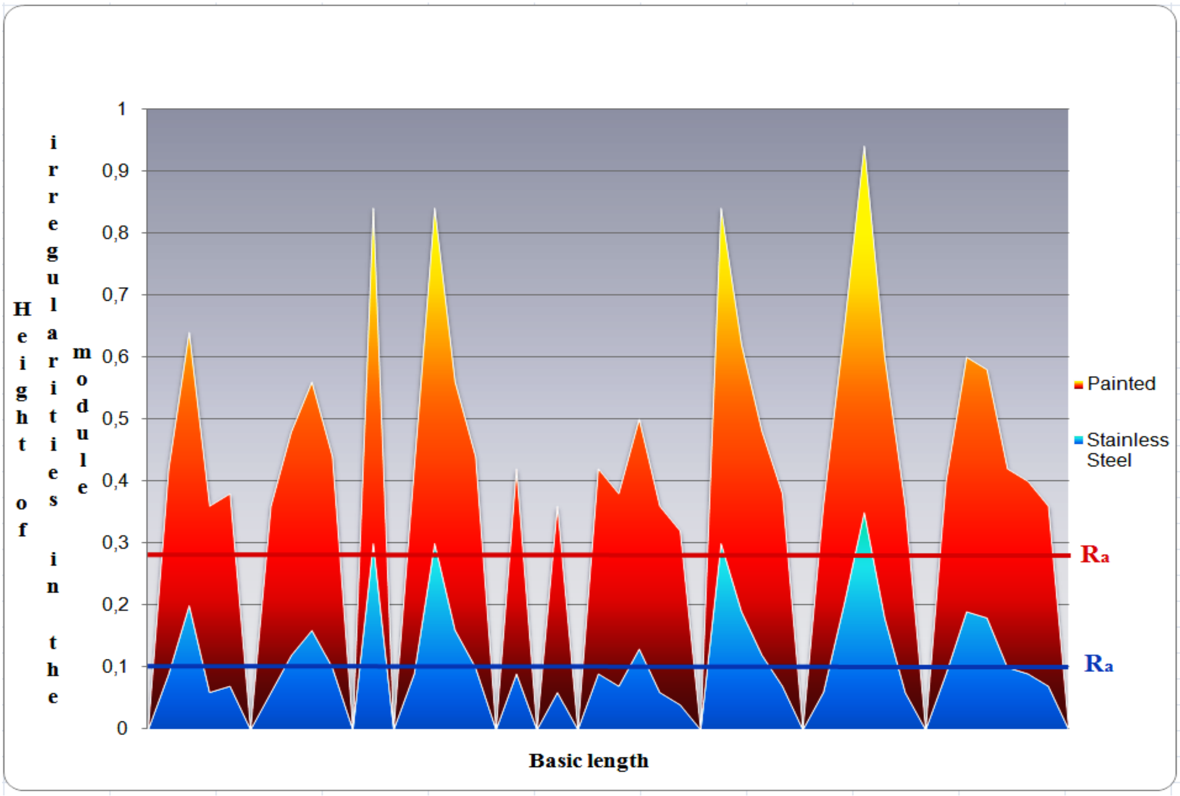


Fig. 10. Representation of average arithmetic deviation, reflecting the surface asperities.

According to the mechanical theory connection [1] the joint between the bearing surface and adhesive (or any coating, paint) is made by infiltration of the adhesive into the pores, asperities (roughness) of bearing surface (Fig.11.).

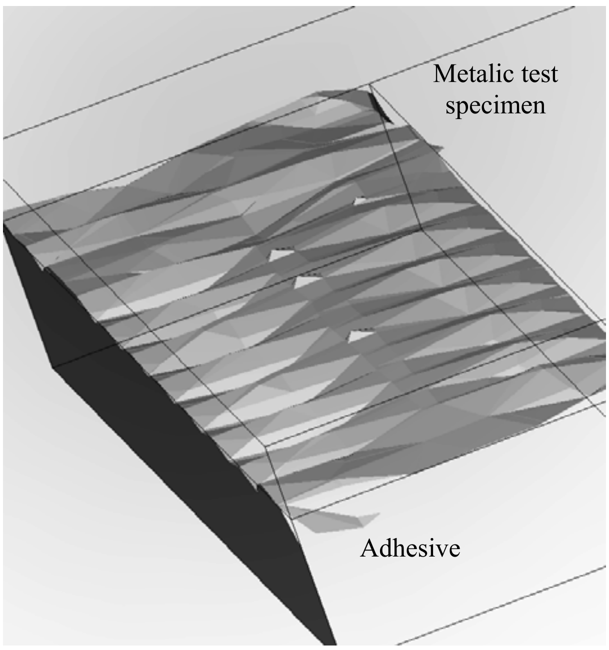


Fig. 11. Simulation of adhesive infiltration.

A relatively new scientific branch Surface Engineering deals with the theoretical basis of bonding technique, which is oriented towards modifying properties of the superficial parts to improve their functional performance. [6]

4. PREPARATION OF TEST TUBES

Test tubes are prepared in accordance with STAS standards 12310/1-85, SR EN 15434+A1:2010 (Annex D), SR EN 14869-1:2010 and DIN 53281 (Fig.12.).

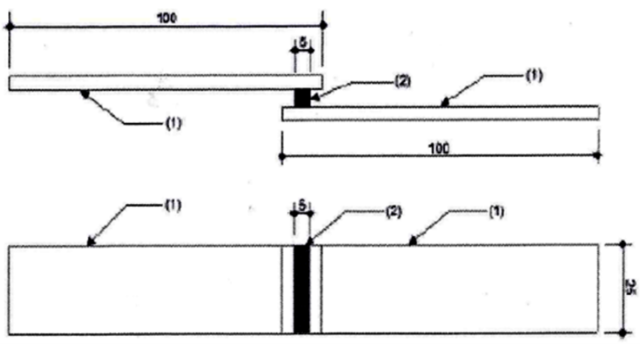


Fig. 12. Test tube in compliance with SR EN 15434+A1:2010.

The research and studies conducted so far to joint bonding by overlapping were studied the same types (composite) of materials having the same thickness.

The distribution of peak voltage are displayed.

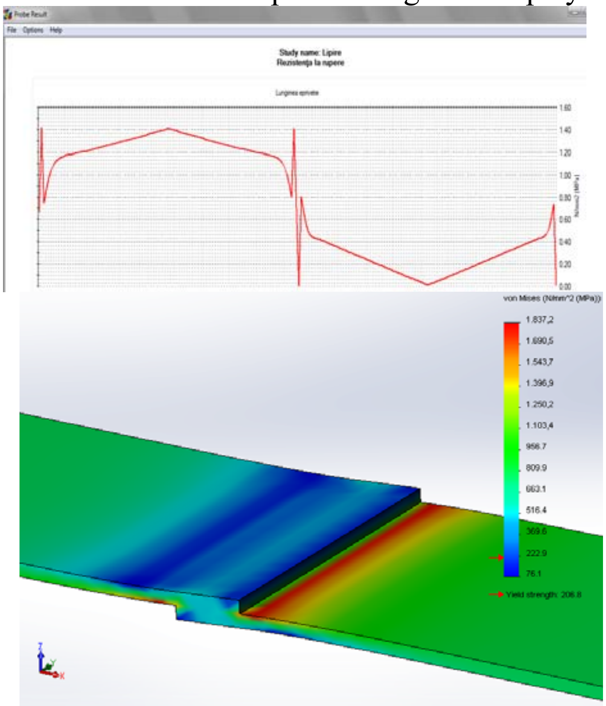


Fig. 13. Distribution of peak voltage at gluing by overlapping along the test tubes, using a thin layer of adhesive in the contact area by applying 100 N traction force.

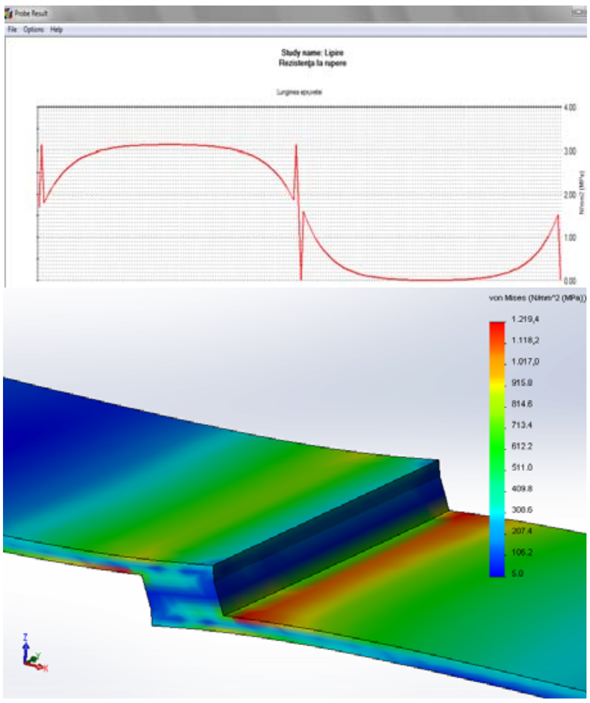


Fig. 14. Distribution of peak voltage at gluing by overlapping along the test tubes, using a coarse layer of adhesive in the contact area by applying 100 N traction force.

Following the diagrams obtained (Fig.13. and Fig.14.) we can notice the influence of the bending moment along the test tube. Moreover, we can see fixed areas (abutting ends and overlapped glued branch), a jump occuring near them.

Considering the studies conducted so far we investigate something new, using the overlapping joint bonding but with two different materials of different thicknesses (metal +adhesive+ glass) (Fig.15.).

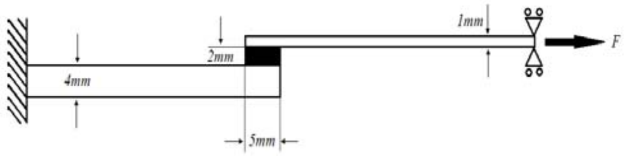


Fig. 15. Positioning and force infliction on studied test tubes.

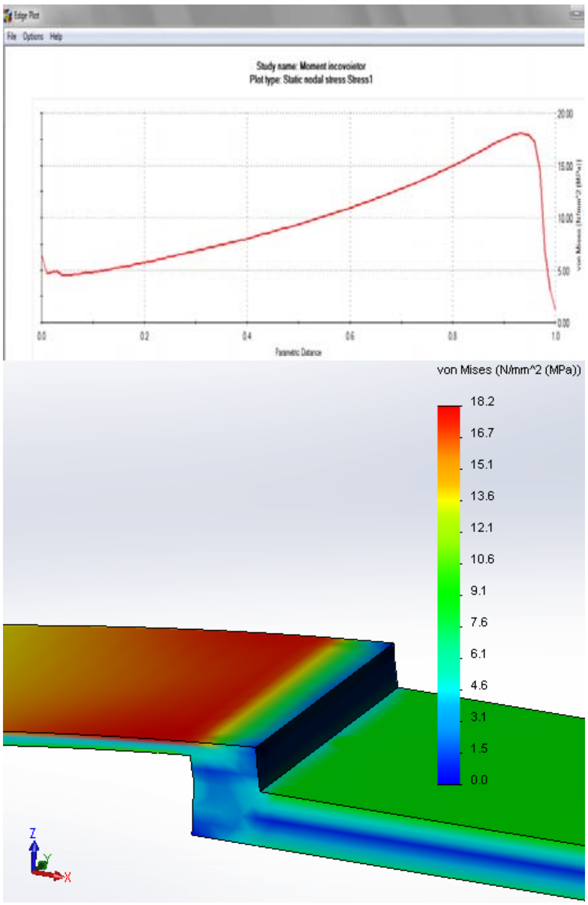


Fig. 16. Distribution of peak voltage at gluing by overlapping along the metal test tubes, using a coarse layer of adhesive in the contact area by applying 100 N traction force.

Due to the fact (Fig.16.). the glass ceramic test tube is a rigid material and has high tensile resistance (tear), it does not present any structural modification (bending) following the applied force. However, test tubes made of metal having a high bending near contact interface and decreasing towards the end of the test tube gives the impression of autocentering. To elliminate this tendency which has impact on the test tube (bending moment),we will use an addition of balancing to perform tensile tests (Fig.17. and Fig.18.).

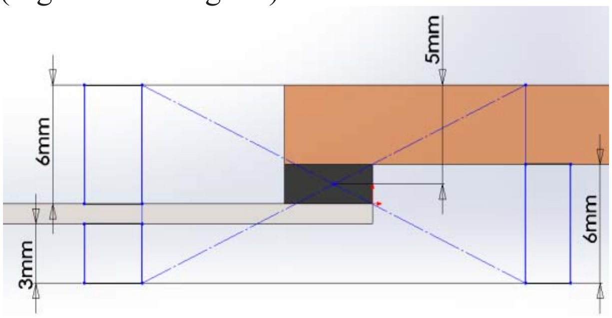


Fig. 17. Calculation of addition for balancing.


Fig. 18. Calibrated test tubes.

5. TRACTION ATTEMPTS

Tensile tests for bonding assembly were performed in the laboratory of UTC-N, Faculty of Mechanical Engineering (Fig.19.).

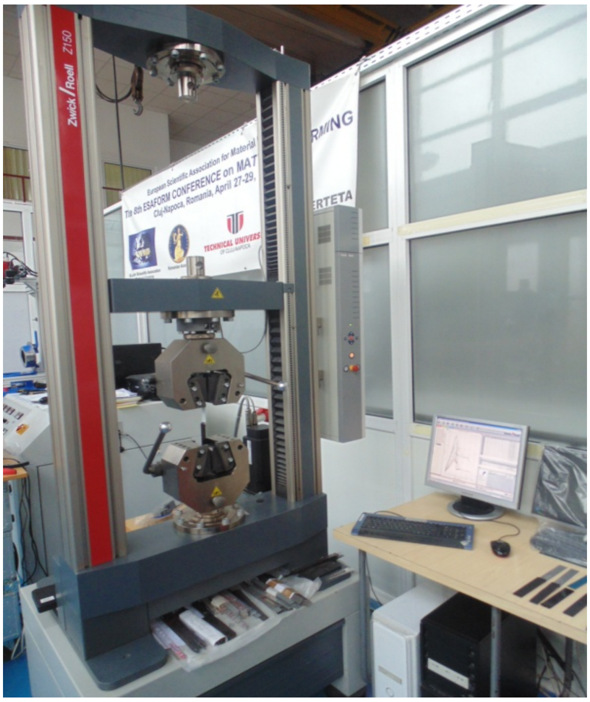


Fig. 19. The machine for tensile testing: Zwick/Roell 150 kN.

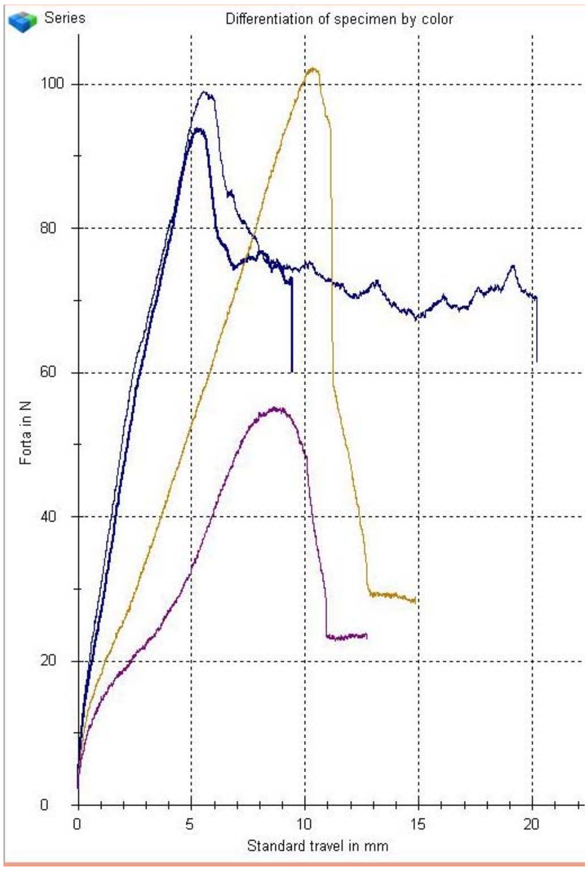


Fig. 20. Tensile curves obtained from stainless steel test tubes.

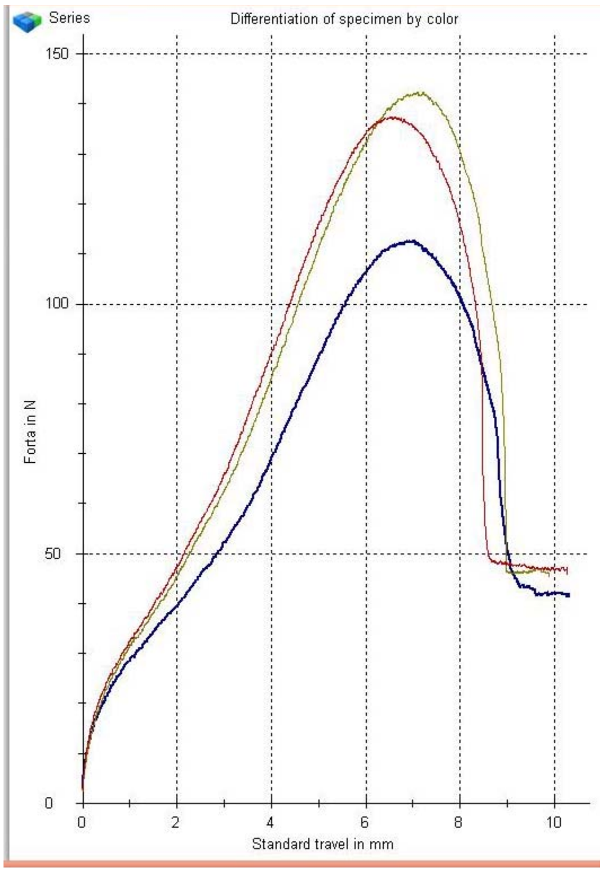


Fig. 21. Tensile curves obtained from metal test tubes painted in electrostatic field.

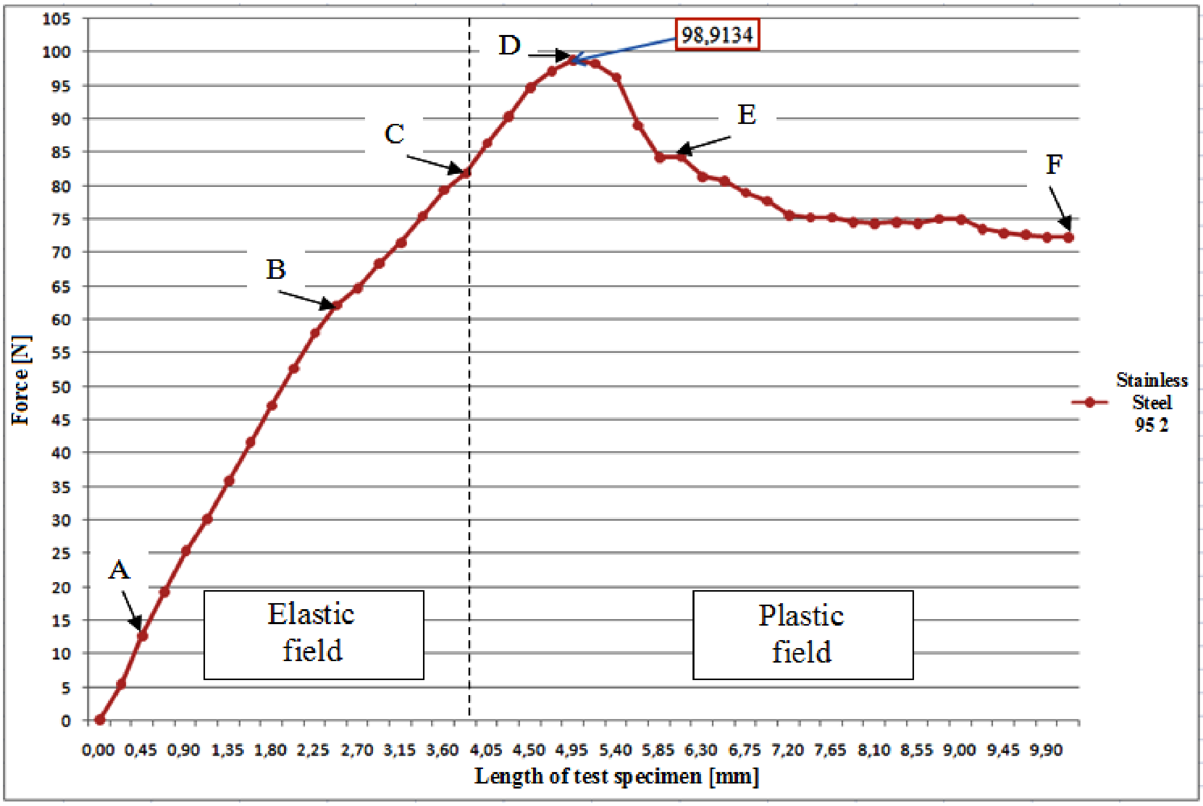


Fig. 22. Stages of test tubes deviation process at traction tests.

Point corresponds to the initial situation, where there are no tensions or deformations in the test tube. $\epsilon = 0$

In the first portion of the curve, the two sizes grow simultaneously, but the rate of growth is higher. In addition, the dependence of the two sizes is linear to the point corresponding to the *limit of proportionality* σ_p (Fig.22.).

Point ordinate, to which the material acts perfectly elastic, after unload (force removal) the test tube regains its original length, it is called *elastic limit* σ_e. (Fig.23.).

Starting from the point, the curve will tend to continue in a direction parallel to the x-axis, because deformation increases without force growing substantially (it is said that the material „flows"). This area marks the entrance to the plastic deformation of the material and proper tensile point is called *flow limit*.

Then an increase point of curve follows, without proportionality between the two sisez, which end in the maxim point, considered to be *tear limit* σ_r or tensile strength of the material tested.

Near the point, that is the maximum amount of force, it is found that in a certain portion of test tube its cross-section decreases, *the bottleneck point*, a phenomenon that sharpens then until *breaking* point. The applied force decreases, leading to a descending path of the curve. [9]

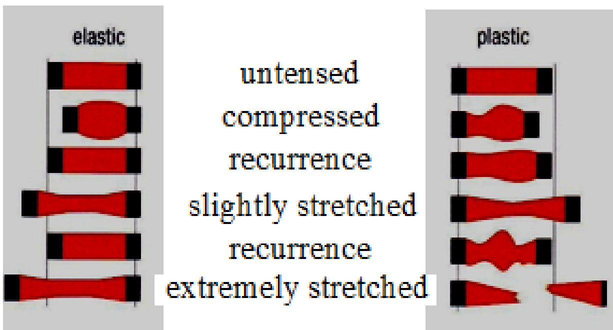


Fig. 23. Representation of difference between elasticity and plasticity.

Table 1.

Experimental results from the tensile test, stainless steel test tubes + adhesive + glass

Test tube no.	F_{max} $[N]$	ΔL $[mm]$	ϵ $[\%]$	σ_c MPa	σ_r MPa	E MPa

1	93.79	4.5	90	8.022	9.379	0.2913
2	98.91	5.2	104	8.191	9.891	0.2702
3	102.22	10	200	9.003	10.222	0.0986
4	54.93	7.5	150	4.798	5.493	0.1024
5	98.72	5.5	110	8.424	9.872	0.2116

Table 2.

Experimental results from the tensile test, painted test tubes + adhesive + glass

Test tube no.						
1	112.53	5.2	104	9.954	11.253	0.2737
2	141.80	4.9	98	11.779	14.180	0.2837
3	137.08	5.2	104	11.562	13.708	0.2758
4	141.99	5.1	102	11.463	14.199	0.2705
5	136.82	5	100	11.223	13.682	0.2881

Following tensile testing carried out at traction, the values obtained (Table 1 and 2) were higher and closer to one another at dyed test tubes, therefore we can say that a treated surface (painted in electrostatic field,) ensures a better link and uniform due to cohesive forces. In the case of stainless steel test tubes ( ), which were only degreased and cleaned of impurities, different results were obtained with lower values.

Fig. 24. Test tubes of stainless steel material after tensile tests.

Analyzing the stainless steel tests tubes following tensile tests (Fig.24.), fractures were found in contact interfaces on the metal side, due to low roughness not providing sufficient bond strength (cohesion) sufficient, reflecting the different values obtained.

Fig. 25. Test tubes of painted material after tensile tests.

Analyzing the painted tests tubes following test traction (Fig.25.), cohesion fractures were found due to higher roughness of test tubes made of steel, ensuring a sufficient bond strength near contact interfaces.

6. CONCLUSIONS

During research conducted at the overlapping joint bonding, important factors which have a decisive role, influencing the mechanical properties were discovered (breaking).

To obtain a sufficiently strong glue joint degreasing and cleaning contact interface of impurities is not sufficient.

Surface roughness is made up of all microirregularities, these irregularities are relatively small in relation to their depth, but have an important role to achieve a strong bond.

The higher the surface roughness or asperities the stronger the cohesive force penetrating the adhesive deeper into the bonding material.

Near the contact interface is necessary to have a minimum gap of adhesive that ensures an even distribution of the workload. Uniform distribution of workload is influenced by the thickness of the adhesive gap changing the bending moment as in the cases presented.

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CARACTERISTICI MECANICE ALE ÎMBINĂRII PRIN LIPIRE CU ADEZIV SINTETIC A METALELOR CU STICLĂ-CERAMICĂ

Rezumat: *Lipirea cu adeziv pe bază de materiale sintetice a câștigat în ultimul deceniu un câmp larg de utilizare, la îmbinarea tablelor sau pieselor metalice, nemetalice sau combinate, îndeosebi în construcția ușoară și mecanică fină, dar și în construcția de mașini. În locul stratului de metal sau aliaj de lipit, intervine un strat subțire de adeziv care, după aplicare, se întărește și preia forțele exterioare prin rezistența mecanică datorită coeziunii din masa lui, cât și prin adeziunea dintre adeziv și suprafețele de îmbinat. Lipirea cu adezivi reprezintă un procedeu cu aplicare largă pe plan mondial. În foarte multe cazuri înlocuiește îmbinarea clasică (sudarea, nituirea) și permite îmbinarea materialelor cu structuri diferite, ca și în cazul studiat (metal cu sticlă). Conform teoriei legăturii mecanice îmbinarea dintre suprafața portantă și adeziv (sau orice acoperire, vopsea) se realizează prin infiltrarea adezivului în porii, asperitățile (rugozitatea) suprafeței portante. Însă această teorie nu poate fi generalizată, pentru că se poate realiza o îmbinare lipită puternică și în cazul materialelor cu suprafață netedă (de exemplu: sticlă, plăcuțe semiconductoare de siliciu). Cu bazele teoretice a tehnicii de lipire se ocupă o ramură științifică relativ nouă, ingineria suprafețelor (surface engineering, surface science).*

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