THE 7TH INTERNATIONAL CONFERENCE RESEARCH AND DEVELOPMENT OF MECHANICAL ELEMENTS AND SYSTEMS

EXPERIMENTAL DETERMINATION OF STRESS CONCENTRATION INFLUENCE ON WELDED CONSTRUCTIONS STABILITY

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Abstract: *Welded construction working properties are highly influenced by the stress and strain distribution in welded joints zones. Stress and strain distributions are determined by stress concentration provoked by geometrical discontinuities and heterogeneous of material. Stress concentration changed the stress distribution, position of maximal stresses and, by that, the position of danger cross section zone which act as damage and integrity safety risk. This paper deals with experimental determination of stress concentration influence on welded constructions integrity. The experimental procedure was done on welded joints models in static load conditions on samples made of commonly used steel strip profile. Experimental procedure was conducted on existing testing devices in Welding Laboratory and Material Testing Laboratory at the Faculty of Mechanical Engineering in Kragujevac. The experimental procedure enclosed the experimental determination of real material properties, so as experimental determination of strength parameters of welded samples with butt joint. Tensile strength, yield strength and elongation of welded models with butt joint and circulars holes in axle, as additional stress concentrator, was experimentally determined in order to point out the losses in mechanical properties, dominant stress concentrator and position of critical cross section. After this experimental procedure stage, tensile strength, yield strength and elongation where determined on samples with different geometrical form, strip with welded butt joint, circulars holes in axle and concave sides. This experimental procedure stage was done to establish relationship between external geometrical forms in welded joints zones and stress concentrations. The aim of this paper is to analyze influence of stress concentration to the resistance of welded structures. Stress concentration was analyzed by experimental approach objected to include as much influential factors as it is possible. The main objective of stress state distribution is creating the precise analytic model and to obtain the relevant data and information for constructions evaluating and optimizations, so as to perform integrity, safety and reliability analysis. This paper pointed out the necessity of analyzing the welded constructions on different dimension levels. Further investigations in this area have to be continued trough development of numerical model of the welded construction which will, in involvement with adequate software, complete the experimentally obtained results.*

Key words*: welded joint, stress concentration, yield strength, tensile strength, and elongation.*

1. INTRODUCTION

The problem of stress concentration in mechanical constructions is present at the calculation and definition of maximum stress, identification of the critical section especially in parts of complex geometric shapes, so the determining the influence of stress concentration on the behavior of elements and structures is a very important stage in the consideration of structural stability. An exact analysis of complex stress states in welded mechanical structures with unavoidable existence of inhomogeneity of material, that is the source of stress concentration, represents the condition of integrity analysis of the observed construction [1, 2]. Demands for improving energy efficiency and increasing price of basic materials cause mass reduction of welded mechanical constructions. Construction solutions of reduced mass are not of the same shapes and dimensions as the constructions that change functionally, therefore the stress state in which they are, is more complex. Besides the tendency to mass reduction, there is a general tendency to geometric dimensions reduction, which automatically causes the stress increase and stress state becomes more complex, and thus increases the risk of the initiation and development of cracks as well as fracture, which are, to the highest degree, caused by stress concentration. The stresses within the welded joints of machine constructions are of variable character with low or high number of changes which further increases the danger. Increasing the number of changes of stress character and increasing the stress level cause the increased risk of occurrence and development of fatigue cracks and the occurrence of fracture. Reason for increase of stress level in modern welded mechanical structures is the reduction of degree of safety. The lower degree of safety is used consequently by reducing weight and reducing costs without increasing safety risks. Efficient and reliable methods for stress state analysis conditioned by stress concentration represent the basics for the assessment of structural integrity of welded constructions. Together with the development of technology, demands for improving the exploiting characteristics also increase, so the welded mechanical structures are subject to large variations in a wider range of loads, and thus creating the need to use materials with better mechanical properties. These materials are difficult weldable, by the rule, and have increased sensitivity to stress concentration, which further increases the importance of stress state analysis in the zones of stress concentration. Market requirements condition the improvement of technology and the use of advanced welding processes. Requirements and expectations of society for increased safety while increasing the risks are another important aspect of determining the stress state distribution in parts of welded mechanical construction, particularly in the areas of stress concentration. Welded structure is a complex system that can be considered from many aspects. The common factor in all welded constructions is the welded joint by which these structures are formed and shaped. Welds are sources of stress concentration by their nature so the determination of the stress state requires a complex analysis of many factors [3, 4, 5 and 6].

2. STRESS STATE DUE TO LOCAL STRESS CONCENTRATION

Theoretical and experimental investigations have shown that the nominal stresses are different from the actual stresses on the zones of geometric and structural discontinuities of the examined elements of constructions. Any change in shape or discontinue causes the redistribution of stress state within the loaded element and therefore represents a source of stress concentration due to the diversion and densification of stress lines. Stress concentration is caused by, besides the shape of loaded element and inhomogeneity of material, with other structural discontinuities. The welded joint itself, by its nature, is a source of stress concentration as a result of applied technology of welding. Zones of element joints of welded constructions are multiple areas of stress concentration and they determine the behavior and stability of the entire constructions with their characteristics. Errors in the joints, cracks and sharp cuts, which most often exist in these zones of stress concentration with a high level of load, are dangerous spots that cause the loss of structural integrity. Type of load also causes a different stress concentration so that in case of tension the stress concentration is the highest while slightly lower stress concentration is caused by bending and the lowest by torsion. Welded joints are zones with high residual stress level as a consequence of applied welding procedure. Residual stresses have great influence on the properties, quality and exploitation characteristics of mechanical structures made by technological process of welding. Stress state that acts within the part of the observed machine construction as a consequence of external load is superimposed with the stress state caused by the residual stresses [7 and 8].

2.1. Methodology and object of examination

Model tests were carried out on specimens bars made of a strip profiles of material Č0361, chemical composition 0.17% C, 0.05% S, 0.05% P, 0.007% N, which is used for responsible welded structures in which there is no risk of brittle fracture. This is the carbon steel of required quality with the following characteristics: tensile strength Rm = 370-450 MPa; yield point ReH = 240 MPa (thickness s < 16 mm), that is ReH = 230 MPa (at 16 < s <40 mm) and allowed elongation $A_{5,\ 65\%}$ = 23 %. For model preparation, specimens bars are welded in protective atmosphere of CO_2 with flow rate 9 l / min, welding device VARMIG 400 D 42 and wire electrode ESAB AUTROD 12:51, d = 1 mm, the specification EN 440, from ESAB producers, Sweden. Welding parameters are: welding current I = 105 A, welding voltage U = 21 V and welding speed v_z = 28 m/h. Specimen bars were tested on mechanical loading machine which operation was achieved through the worm transmission and the winding spindle. Winding spindle is in relation to moving jaws of the machine. The machine is equipped with a device for registering force dependence on elongation.

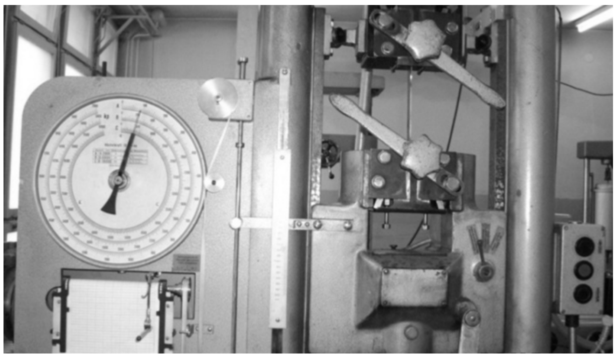

Fig.1. Mechanical loading machine with measuring device

During the testing, mechanical loading machine was loaded in the range up to 5 kN with a force increase speed adequate for static tests; l0 mm/min. Experimental testing was performed at the Laboratory for welding and Laboratory for machining materials using existing equipment for testing of Mechanical Engineering Faculty in Kragujevac.

3. EXPERIMENTAL TESTING PROCEDURE

For experimental testing of stress concentration influence on mechanical properties of the models, specimen bars were used, firstly with flat sides, with no welded joints, then with welded joint and, at the end, welded joint and the circular holes in the axis. The shape and dimensions of specimen bars examined, with the flat sides are shown in Fig.2. Testing was conducted using a pre-defined procedure on a series of five specimen bars for each configuration of stress concentrator. Force on the yield limit and tensile strength were measured. Elongation to the limit of breaking was determined. The obtained results show very small relative exceptions and can be taken as relevant for further analysis.

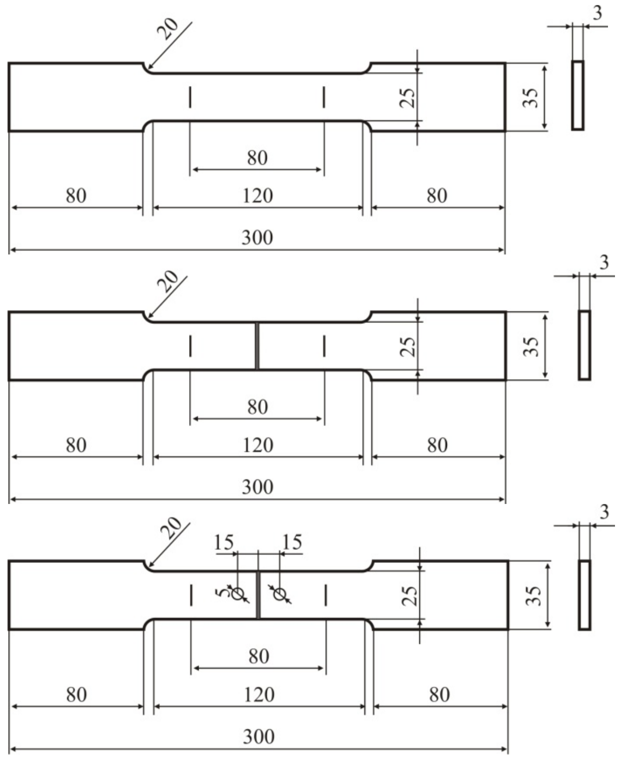

Fig.2. Shapes and dimensions of tested specimen bars with flat sides

Mechanical properties comparison of specimen bars made of base material, with the weldment and weldment and holes on the axis are shown in Fig.3, 4 and 5.

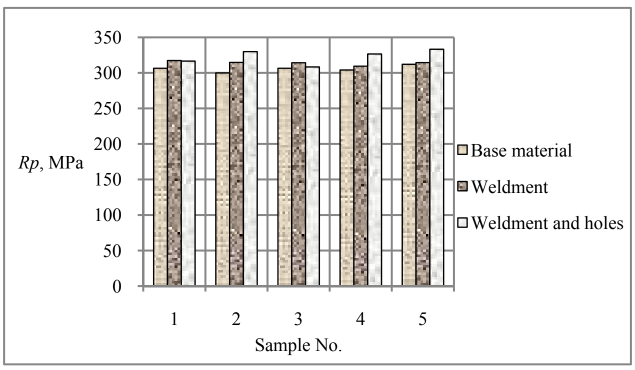

Fig.3. Yield limit for specimen bars with flat sides

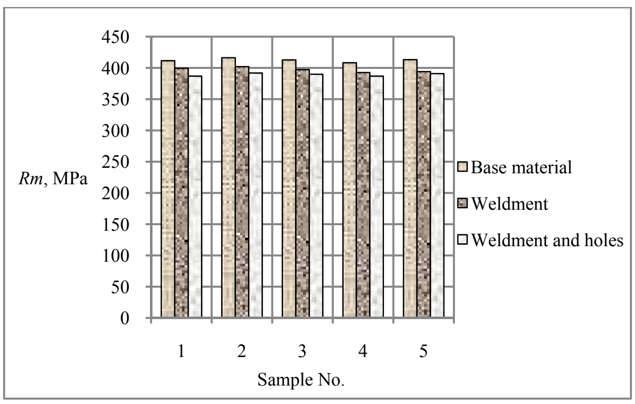

Fig.4. Tensile strength for specimen bars with flat sides

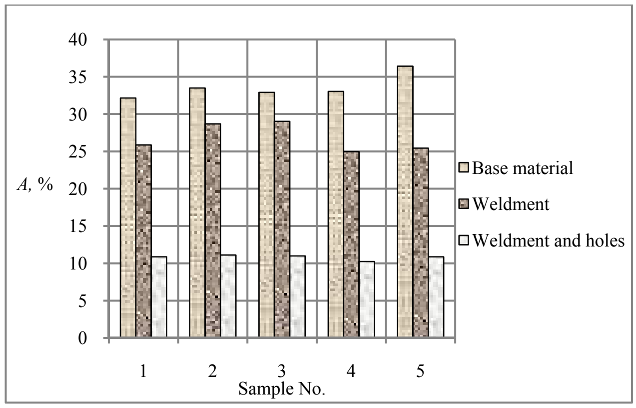

Fig.5. Elongation for the specimen bars with flat sides

The second part of experimental testing in this study was conducted to determine the mechanical properties of specimen bars with concave sides, with no welded joint, then with welded joint and at the end with welded joint and the circular holes in the axis. The shapes and dimensions of the specimen bars examined, with the concave sides are shown in Fig.6. Testing was conducted using a pre-defined procedure on a series of five specimen bars for each configuration of stress concentrator and the force values on the yield limit and tensile strength were obtained, and later elongation to the limit of breaking was measured. The obtained results show very small relative exceptions and can be taken as relevant for further analysis.

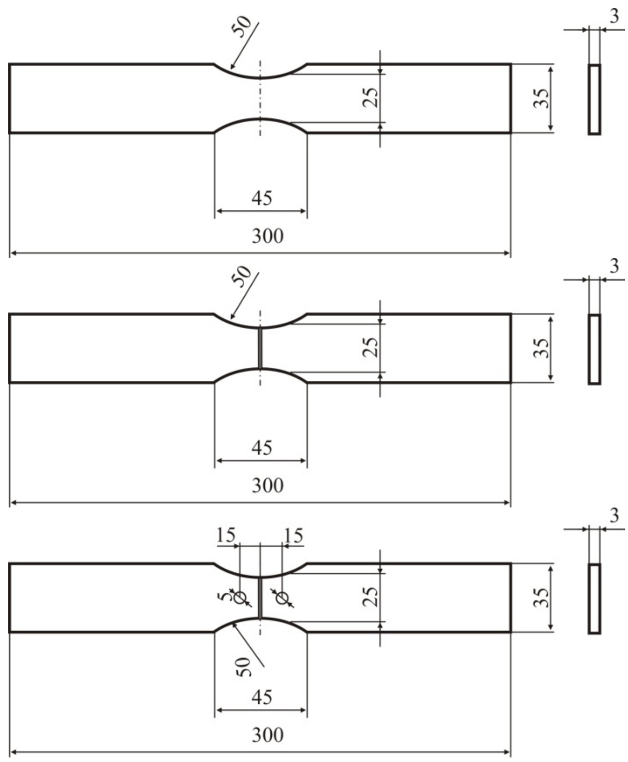

Fig.6. Shapes and dimensions of the examined specimen bars with concave sides

Comparison of the experimentally obtained results of mechanical properties of specimens with concave sides of the base material, with weldment and weldment with holes in the axis are shown the diagrams in Fig.7 and

Fig.8. Comparison of achieved elongation of specimen bars with concave sides to the point of breaking of the base material, with weldment and weldment with holes in the axis are shown in the Fig.9.

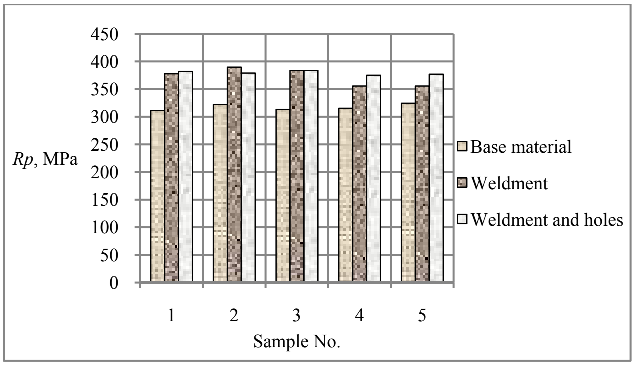

Fig.7. Yield limit for specimens with concave sides

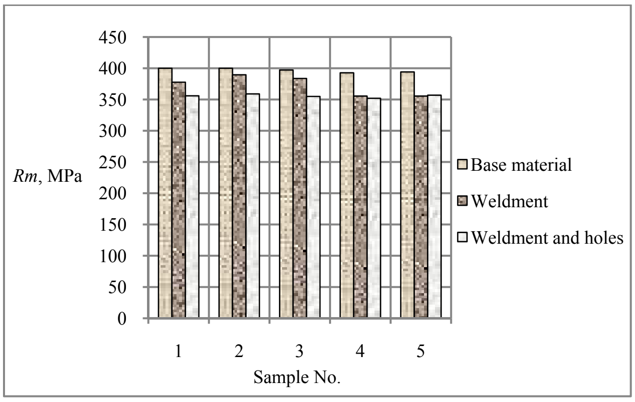

Fig.8. Tensile strength for specimen bars with concave sides

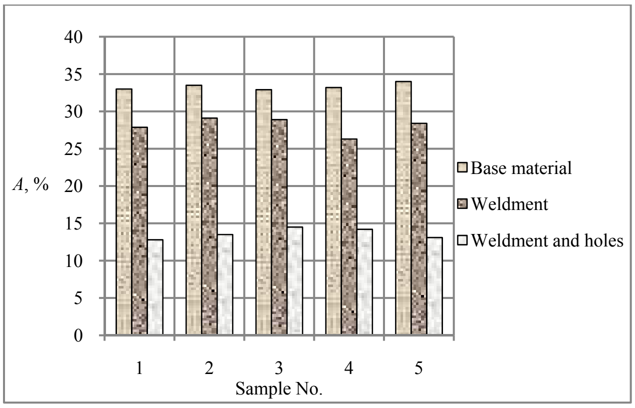

Fig.9. Elongation for specimen bars with concave sides

Mechanical properties comparison of specimens with flat and concave sides without additional stress concentrators are shown in the diagrams in Fig. 10. and Fig.11.

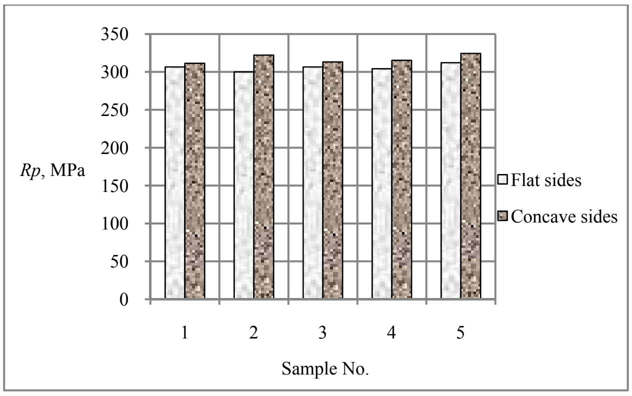

Fig.10. Yield limit for specimen bars with flat and concave sides

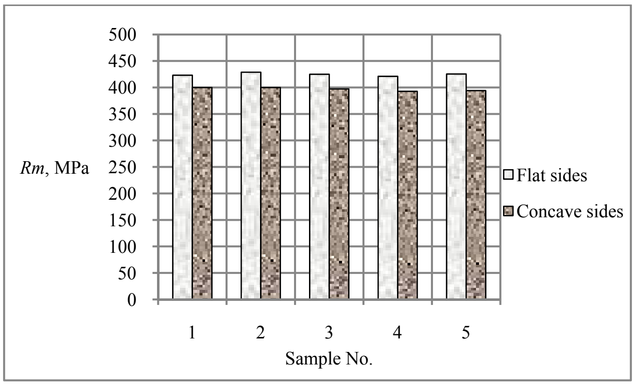

Fig.11. Tensile strength for specimen bars with flat and concave sides

Mechanical properties comparisons of the specimen bars with flat and concave sides with welded joint are shown in Fig.12 and Fig.13.

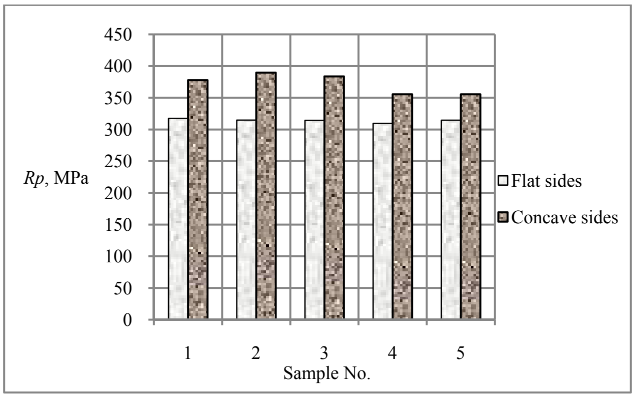

Fig.12. Yield limit for specimen bars with weldment and flat and concave sides

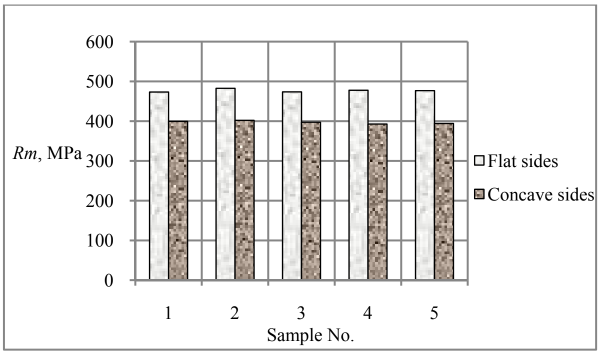

Fig.13. Tensile strength for specimen bars with weldment and flat and concave sides

Results of comparison of experimental testing of mechanical properties of specimen bars with flat and concave sides of the welded joint and the circular holes are shown on diagrams in Fig. 14 and Fig. 15.

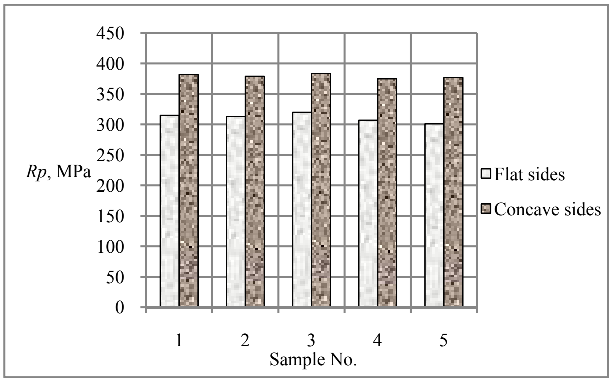

Fig.14. Yield limit for specimen bars with weldment and holes, with flat and concave sides

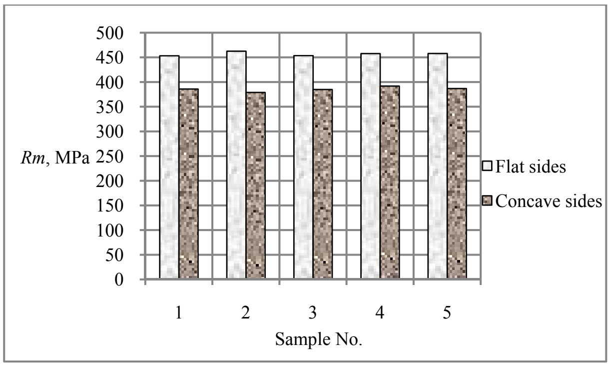

Fig.15. Tensile strength for specimen bars with weldment and flat and concave sides

The obtained results show very small relative exceptions and can be taken as relevant for further analysis.

4. EVALUATION OF THE OBTAINED RESULTS

The material used for preparation of samples used in testing is commonly used structural steel of commercial quality that fully meets the required mechanical properties, both in terms of mechanical strength and plasticity, which was experimentally confirmed. Mechanical properties of welded joint, during tests, remain within the limits of base material, so that by the appropriate choice of parameters for technological welding process, good utilization of the mechanical characteristics of the used base material can be achieved [15 and 16]. In Fig. 16, the appearance of specimen bar with flat sides, welded joint and the circular holes in the axis after executed testing is shown.

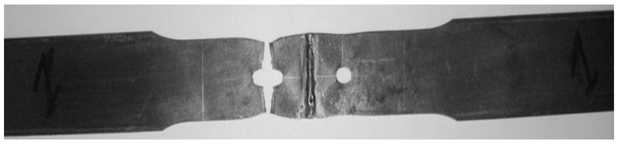

Fig.16. Appearance of specimen bar after testing with flat sides

Welded joints plasticity is lower than the plasticity of the base material which is proven experimentally (Fig. 16), in accordance with current literature sources related to this area [9, 10, 11 and 12]. By testing the specimen bars with flat sides, welded joint and circular holes in the axis, tensile strength values are reached, which show a clear tendency of descent of mechanical properties due to stress concentration. The position of breaking zone shows that the highest stress concentration occurred in the area of holes for specimen bars with welded joints and holes in the axis exposed to tension (Fig. 16). The highest stress level on the yield limit and the highest plasticity are shown by the specimen bars with welded joints and holes in the axis. Due to stress concentration near the dominant sources – holes, formation of positive zones for material yield occurs, and from the view of plasticity, these concentration sources affect the increase of deformations that occur until the final breaking of specimen bar (Fig.16). The obtained results are in agreement with other literature sources that analyze the stress concentration area and stress-strain state of metallic materials. When examining the mechanical properties of specimen bars with concave sides without weldment, achieved stresses on yield limit and tensile strength show the trend of slight decline, so that the stress concentration caused by the shape of tested specimen bars can be ignored. In testing of specimen bars with concave sides and welded joint, values on the yield limit and tensile strength of specimen bar show a trend of mechanical properties decline. In Fig.17, the appearance of specimen bar with concave sides, welded joint and the circular holes in the axis after the executed testing is shown.

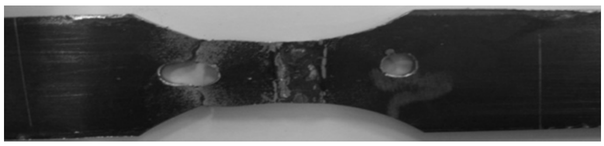

Fig.17. Appearance of the specimen bar with concave sides after the conducted testing

Dominant stress concentration is caused by circular holes which show the position of the breaking zone (Fig.17). The experimental results are in accordance with the results shown in the literature [9, 10, 11 and 12].

5. CONCLUSION

Welded structures belong to the group of complex mechanical structures, and for their proper design, construction and use, a number of influencing factors should be analyzed. The essence of determining the stress state is the formation of the more accurate analytical model of construction and provision of sufficient data and information for the constructural elaboration and a detailed calculation, acknowledgement of technological welding process and its parameters, and performance of construction itself [13 and 14]. Mechanical resistance and stability of welded structures are analyzed and proven by calculation of capacity of welded structure for the anticipated loads and exploitative conditions. In analytical models used for these analyses and calculations, the stress concentration is one of the major factors in determining the correct stress state. Further researches in this area should be continued by developing and obtaining the numerical model of the welded structure which would complete the calculation and confirm the experimental testing with adequate software.

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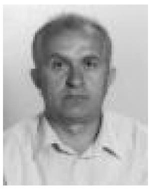

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