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Stress Concentration at Welded Joins of Bucket-wheel Excavator

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Stress and strain distribution in welded joints zone is major influential factor to exploitation properties, safety and reliability of bucket-wheel excavators. Stress and strain distribution in zones of welded joints of bucket-wheel excavator is determined by stress concentration forced by geometrical discontinuities and heterogeneous of material. This paper deals with experimental determination of stress concentration influence to mechanical properties of welded joints models. The experimental procedure was done on welded joints models in static load conditions on samples made of commonly used steel strip profile. The experimental procedure involved determination of material properties and determination of strength parameters of butt joint welded samples with different configuration of stress concentrators. The aim of this paper is to highlight the importance of welded joint properties to the resistance of bucket-wheel excavator' welded structure. Stress concentration was analyzed by experimental approach objected to include as much influential factors as it is possible. This paper pointed out the necessity of analyzing the bucket-wheel excavator' welded structure on different dimension levels. Further investigations in this area have to be continued trough development of precise numerical model of the bucket-wheel excavator' welded structure which will, in involvement with adequate software simulation, complete the obtained results.

Keywords: Bucket-wheel excavator, welded joint, stress concentration, mechanical properties.

1 INTRODUCTION

Bucket-wheel excavators are heavy-duty engineering vehicles with primary function of earth-moving in mining. The bucket wheel, as one of the integrated components is a large, round wheel with a configuration of scoops which is fixed to a boom with rotation capability. Material is picked up by the cutting wheel and transferred back along the boom. Material is then through the discharge boom received and carries away to an external conveyor system. The main function of counterweight boom is to balance the cutting boom and is cantilevered on the support structure. The support structure laid on the movement systems. The support structure of bucket-wheel excavators is capable of rotating about a vertical axis. The cutting boom can be positioned by rotation up and down. The object of observation in the study presented in the paper is bucket-wheel excavator by FAM at Kolubara, Serbia (Fig.1). The origin equipment consisted of five SRs 1200.24/4 VR FAM-Buckau bucket-wheel excavators, dated in the 1960s. The support structure was ruined in accident in 1995. The massive rebuild was done and the steelwork and support structure were upgraded. The tower and ballast boom from the Type SRs 1300 were fitted which gave better transmission of force for rope guidance and the wheel boom hoisting gear. A new lightweight bucket-wheel drive was used and drive power was increased from 400 kW to 630 kW, capacity was increased from 3450-4000 m^3/h while improving the specific digging force to 1,000 N/cm and belt speed was increased by 15%.

Fig. 1. *Bucket-wheel excavator by FAM at Kolubara, Serbia*

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The support structure of the observed bucket-wheel excavator is typically complex welded steel structure. It is estimated that 70-80 % of the total weight of bucket-wheel excavator consists of steel plates and steel castings with welding as the main joining method. The assessment of properties of the welded joints is in focus of the paper due to facts that the welds are the determining factor of expected life of bucket-wheel excavator. Accordingly, the zones of welded joints are the regions of weakness in a structure and must be fully understood.

During exploitation this welded structure are subjected to severe static and dynamic loading which can result in fatigue damage in the zones of the welds. Due to significance of safety and reliability, design against fatigue failure and developments for improving the fatigue strength of welded structures must be done. Material fatigue is local phenomenon and involves a gradual decline in mechanical properties within exploitation. Failure occurs in local zones of the structure that are subject to high stresses and where weld defects are significant [1, 2, 3, 4 and 5].

2 STRESS CONCENTRATION IN ZONES OF WELDED JOINTS

Changes in shape or discontinues cause the redistribution of stresses within the loaded element and represent the stress concentrators due to the diversion and densification of stress lines. Stress concentration is, also, caused by, inhomogeneity of material, and with other structural discontinuities. The welded joint itself, by its nature, is a source of stress concentration as consequence of applied welding technology. Element joints zones in welded constructions are the areas of multiple stress concentration. The properties of those zones determine the behavior and stability of the entire constructions. 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. Welded joints are zones with high residual stress level as a consequence of applied welding technology. Residual stresses have great influence on the properties, quality and exploitation characteristics of mechanical structures made by process of welding. Furthermore, zones of welded joints determined the safety and reliability of whole welded constructions [6, 7, 8, 9 and 10].

The stresses in the welded joints zones are of highly unpredictable character. Efficient and reliable methods for stress state analysis conditioned by stress concentrations represent the basis for the assessment of structural integrity of support structure of bucket-wheel excavator as welded construction.

3 MODEL TESTING

Due to importance of welded joints' properties model testing of typical joints of bucket-wheel excavator with common configuration of stress concentrators was done. The models for testing were prepared with required geometrical similarity to welded joints of real bucket-wheel excavator construction. Tests were carried out on specimens 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 without risk of brittle fracture. For model preparation, specimens 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 were: welding current I = 105 A, welding voltage U = 21 V and welding speed v_z = 28 m/h. The machine is equipped with a device for registering force dependence on elongation (Fig.2). Force increase speed was adequate for static tests. Experimental testing was performed at the Laboratory for welding and Laboratory for machining materials at Faculty of Mechanical Engineering in Kragujevac.

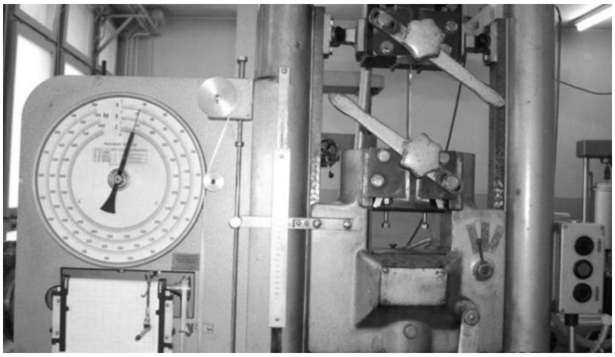

Fig. 2. *Mechanical loading machine with measuring device*

4 PROCEDURES OF EXPERIMENTAL TESTING

For experimental testing of stress concentration influence on mechanical properties of the joints models, specimens were used. Firstly, testing was done on samples with flat sides, with and without welded joints. Then, samples with welded joints and the circular holes in the axis ware tested. At the end, in order to examine the influence of stress concentration due to shapes of welded joints' zones testing were conducted on specimens with concave sides and welded joints and holes in the axis. Shape and dimensions of specimens used for testing are shown in Fig.3. Testing was conducted according to defined procedure on a series of five specimens for each configuration of stress concentrator.

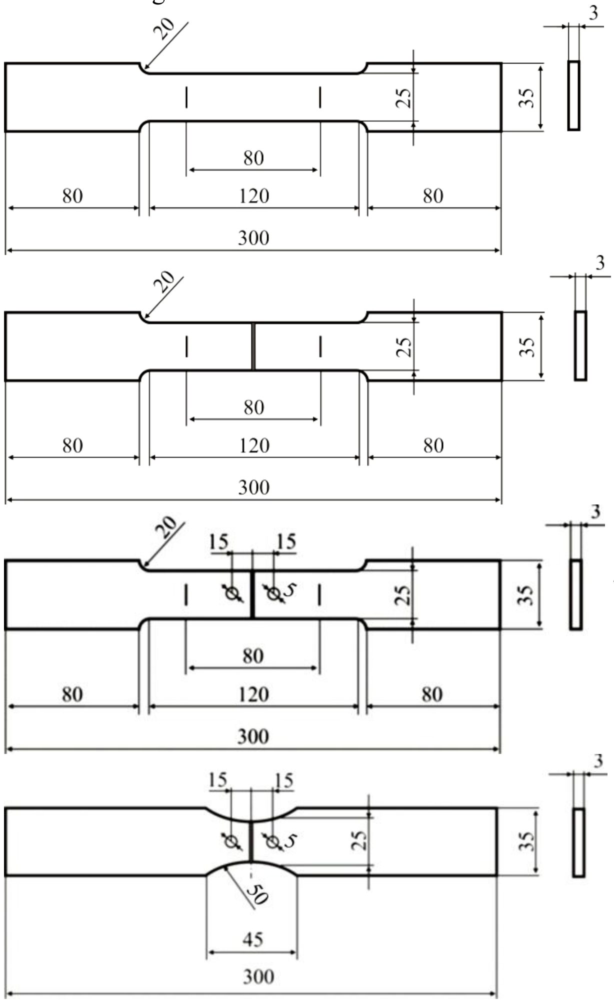

Fig. 3. *Shapes and dimensions of tested specimens*

Force on the yield limit and tensile strength ware measured. Elongation to the limit of breaking was determined. The obtained results show very small relative variations and can be taken as relevant for further analysis. The force dependence on elongation for specimens with parallel sides and welded joint is presented at Fig.4. For specimens with parallel sides, welded joint and holes, force dependence on elongation is presented at Fig.5. Fig. 6. presented force dependence on elongation for specimens with concave sides, welded joint and holes in axis.

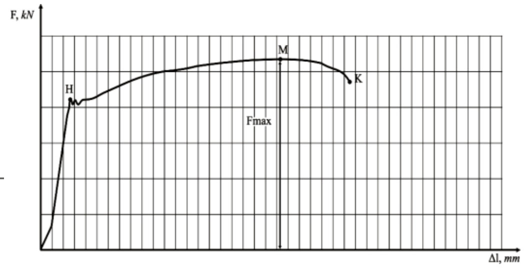

Fig. 4. *Force dependence on elongation for specimens with parallel sides and welded joint*

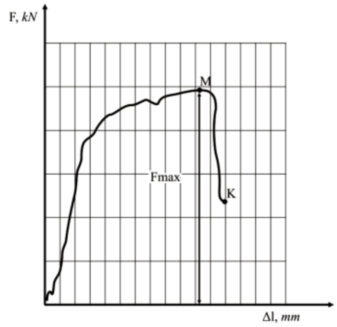

Fig. 5. *Force dependence on elongation for specimens with parallel sides, welded joint and holes in axis.*

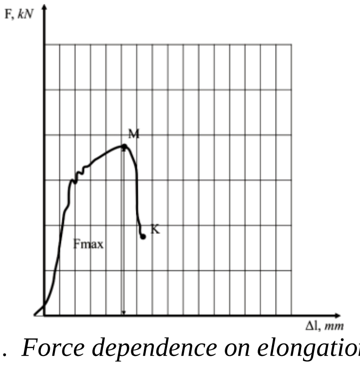

Fig. 6. *Force dependence on elongation for specimens with concave sides, welded joint and holes in axis.*

The presented diagrams showed different material behavior due to different multiple stress concentration within samples. Mechanical properties comparisons of specimens are shown in Fig.7, 8 and 9.

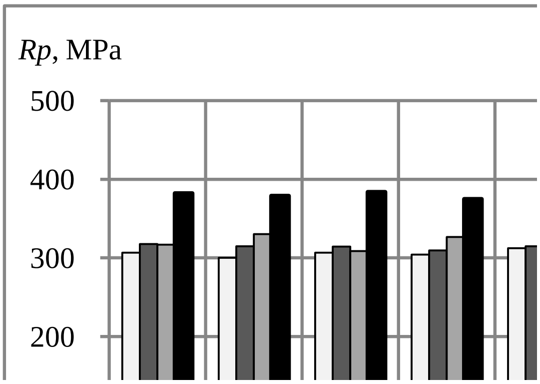

Fig. 7. *Yield limit for tested specimens*

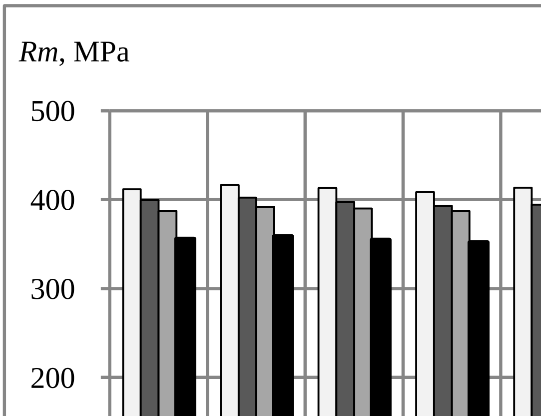

Fig. 8. *Tensile strength for tested specimens*

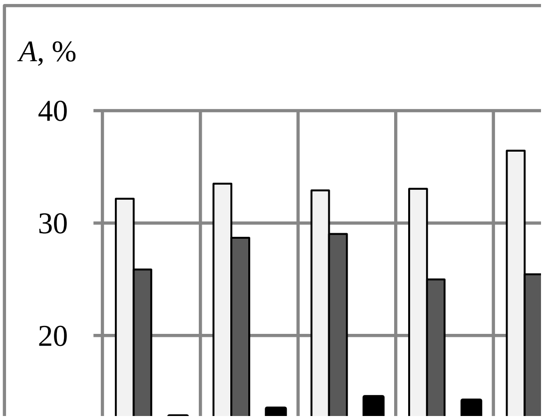

Fig. 9. *Elongation for tested specimens*

Due to very small relative variations obtained results, can be taken as relevant for further analysis.

5 OBTAINED RESULTS EVALUATIONS

The used material for testing is 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 samples with welded joint remain within the limits of base material. By that, it can be concluded that good utilization of the mechanical characteristics of the used base material can be achieved by appropriate welding process. In Fig.10, the appearance of specimen with flat sides, welded joint and the circular holes in the axis after testing is shown.

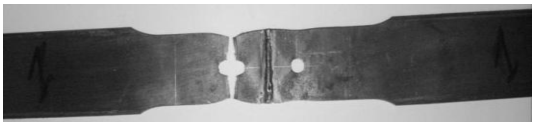

Fig. 10. *Appearance of specimen after testing with flat sides [6]*

The plasticity of welded joints is lower than the plasticity of the base material which is confirmed experimentally (Fig.10), and it is in accordance with current literature sources related to this area [11 and 12]. By testing the specimens with parallel sides, welded joint and circular holes in the axis, the reached tensile strength values show the tendency of decline of mechanical properties due to multiple stress concentration. The highest concentration of stresses occurred in the area of holes for specimens with welded joints and holes in the axis. The position of breaking zone pointed out this fact (Fig.10). Specimens with welded joints and holes in the axis shoved highest stress level on the yield limit and the highest plasticity. These concentration sources affect the increase of deformations that occur until the final breaking of specimen (Fig.10). The self obtained results are in agreement with literature sources that analyze the stress concentration and stress-strain state of metallic materials [13, 14, 15 and 16]. Achieved stresses on yield limit and tensile strength of specimen with concave sides, weldment and holes in axis show the trend of decline, so that the stress concentration caused by the shape of tested specimen can't be ignored. At Fig.11. appearance of specimen with concave sides, welded joint and the circular holes in the axis after the testing is shown.

Fig. 11. *Appearance of the specimen with concave sides after testing[6]*

The position of the breaking zone shows that dominant stress concentration is caused by circular holes (Fig.11). The experimentally obtained results are in accordance with the results shown in the literature [12, 14 and 17].

6 CONCLUSIONS

Present state of the earthmovers, especially bucket-wheel excavator as continuous excavation machines, which is dominant component in mining system, is characterized by progressive growth in dimensions, increase of capacity and permanently improving performances all together with decrease of exploitation costs. This must be followed by proper calculation methods in which zones of welded joints have to be adequately treated. Bucket-wheel excavators belong to the group of complex welded mechanical structures, and for its proper design, construction and use, a number of influencing factors should be analyzed. Welded construction of support system of bucket-wheel excavator is a complex system of heterogeneous elements by dimensions and shapes, structures, mechanical characteristic with complex interactions between those elements. Heterogeneity of welded construction elements provoked its different answers to load. Inhomogeneity of microstructure at zones of welded joints causes additional complexion of stress state. Stress concentration caused by characteristic shape of construction elements completely changed the stress state distribution, position of maximal stresses, and by that the position of danger cross section zone which act as safety risk for damage and integrity of the construction. Distribution of the stress state in welded construction is changeable due to load characteristic. The essence of determining the stress state in welded joints zones is to form its' more accurate analytical model, which will provide data and information for the constructural analysis, elaboration and detailed calculations of bucket-wheel excavator. All that facts are the consequence of the influence of welding join methods and its parameters to the stability and performance of construction itself. Mechanical resistance and stability of support structures of bucket-wheel excavators as welded constructions 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 precise numerical model of welded joints of bucket-wheel excavator which would complete the calculation and verify the experimental model testing.

Safety and reliability requirements for this kind of heavy equipment are very strict. On the other side, maintenance costs of bucket-wheel excavator are very high. Failure costs increase with increased excavation capacity. All the pointed facts impose the necessity or adequate design optimization of bucket-wheel excavator. The design process must be done on adequate capacity calculations and must be verified through numerical simulation and experimental model testing. The whole construction must be treated on different dimension levels in order to enclosed the influence of welded joint zons.

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