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ALTERNATIVE EXPLOSION-FORMED JOINT OF HIGH-STRENGTH TUBE AND SLEEVE

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Abstract: *Structural components from high-strength low-alloyed steels normally cannot be joined using conventional methods like welding. For this reason, an alternative demonstration tube joint has been designed and produced on the basis of plastic deformation. The principle of the joint is plastic bulging of the tube to fill a recess in a collar. The bulging effect is produced by a pressure impulse of an explosion transmitted to the formed piece through water.*

Key words: *joint, explosion, forming, high-strength,*

1. INTRODUCTION

New types of low-alloyed high-strength steels show great potential for replacement of conventional structural steels in various types of structures. In this case, joints between individual components of the structure can become the most problematic locations. High-strength materials are not easily weldable. First, it is due to their chemical composition which itself, in most cases, does not guarantee good weldability. Second, their controlled microstructure completely changes due to welding and has thus different – typically worse – properties in the welded location.

For these reasons, alternative techniques for making permanent joints are sought. Authors of this paper have been seeking low-cost and highly productive alternative methods of making such joints. One of such techniques meeting the required criteria is explosive bulk forming applied in the experiment. In the first step, technological ductility in expansion of the tube wall due to pressure of the explosion gas was examined. The results served for designing the second experiment in making a high-strength tube-sleeve joint with the strength above 1,000 MPa. In order to determine the load-carrying capacity and analyse the failure mode of the joint, it was tested under axial load.

2. EXPLOSIVE FORMING

Man has been using the effects of explosive energy for centuries, particularly in military technology. Explosives and blasting explosives in particular, offer new opportunities for use in forming and welding of metals, as they expand the potential for use of the dynamic pressure caused by the explosive not only in pressing but also in bulk forming, hole making, shearing, etc. Explosive forming has been used in past in rocket and aviation technology for forming sizable structural parts, in rail transport and many other branches of human activity. (Chládek, L et al.,1971; Ezra, A.A., 1973).

Fig. 1 Photograph of the tube expansion test performed by an explosion in a die

SEMTEX S30 was selected for the initial bulk forming tests on tubes. Its name Semtex was formed by joining the words SEMtín (the location of the producer) + EXplosive and became the name of a range of special blasting explosives. Semtex S-type blasting explosive is a special-purpose product for explosive welding of metals, forming of metals and other applications.

In order to determine the elongation or maximum plasticity of a high-strength tube in rapid forming processes, an experiment was carried out involving forming in a die with a cylindrical cavity with a conical 4.5°end (Fig. 1). The test lead to expansion of the tube to a conical shape from the initial 50 mm to the diameter of 67.3 mm. No visible cracks formed in the tube until the diameter of about 60 mm. A preliminary calculation identified the maximum useful deformation of 20%

For the first experiment SEMTEX S30 in the amount of 308.8 g was used. The forming medium consisted exclusively of the products of the detonation. This slightly large amount of explosive was used in order to ensure the complete deformation of the tube along the entire die length.

The findings were a basis for designing and defining the dimension of an alternative joint type and the entire explosive forming process. An electric detonator with about 0.97 g of high explosive was used. The forming medium was water within the tube closed with plugs. Forming with the aid of an explosive and water is highly efficient in energy utilization and imposes lower acoustic loads on the environment. The liquid provides rather uniform effects of pressure throughout the volume to be formed. Besides, the amount of explosive is more than one order of magnitude lower, which reduces the cost. In this experiment, the tube with the above amount of explosive has filled the recess in the sleeve perfectly. (Vacek, J., 1998; Pantoflíček, J. & Lébr, F., 1967).

3. COMPRESSION LOAD-CARRYING CAPACITY TEST

A compression load-carrying capacity test was performed on the experimentally prepared joint. The specimen with the joint was supported under the tube in order to allow the shear force to act on the entire surface of the sleeve. The load-carrying capacity of the was about 30 kN. The joint resisted the load up to 60 kN. This load did not cause a catastrophic destruction either, as stable plastic deformation occurred with the extension path of about 20 mm. The test was performed under quasi-static conditions at room temperature. The evaluated parameter was the dependence of the loading force (kN) on the cross-bar movement (mm) – Fig. 3.

Explosive forming causes strengthening mainly in the impact area of the outer tube surface on the inner surface of the sleeve. This locally increases the strength of the tube and improves the load-carrying capacity of the joint. The compression load-carrying capacity test caused a reverse

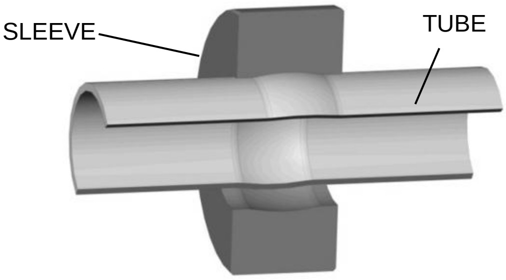

Fig. 2 Joint in the section after explosive forming

forming of the bulged area into a cylindrical shape (Fig. 6). This indicates that the load-carrying capacity of the joint can is governed to a great extent by the flow stress of the tube material.

4. METALLOGRAPHIC ANALYSIS

Metallographic observation and hardness profile measurement were performed after the compression load-carrying capacity test. The material of the tube consisted of fine-grained tempered martensite with uniformly dispersed fine carbides (Fig. 4). The prior austenite grain size was about 10μm.

The material of the tube was subjected to a number of deformations which caused local strengthening. The tube was formed when manufactured and, again, in the explosive forming process. Finally, it was also deformed during the load-carrying capacity test. These changes are apparent in the hardness profile. The hardness profile was measured from the bottom edge of the tube to the location of the original joint prior to destruction (Fig. 6) where there is the first peak in the distance of 35 mm, indicating the explosive forming operation. Another peak in the distance of 20 mm represents the deformation in the mechanical testing shop.

5. FEM SIMULATION

Assessment of the load-carrying capacity of the joint requires identification of the limit loading states which lead to progressive deformation of the material. Equally important is the analysis of the failure which, in this case, takes the form of plastic deformation. As the interaction of the components of the joint cannot be measured from outside, FEM simulation has been used.

Thanks to the axial symmetry of the joint, the problem could be solved as an axially symetric calculation offering sufficiently fine mesh with fairly low number of elements. Difficult aspects of the problem resulted from non-linear features, such as the contact points between both components, and the elastic-plastic material of the tube. Data characterizing the material was defined by means of a stress-strain curve for the given state of the material and the corresponding strengthening. Boundary conditions were identical to those used in testing of the joint in testing equipment.

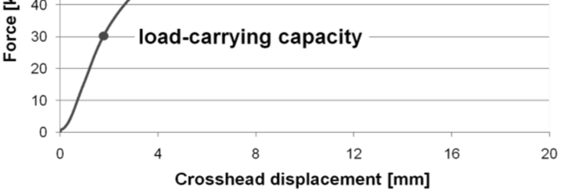

Fig. 3 Behaviour of the joint under load

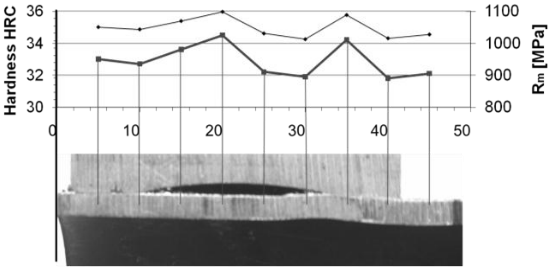

Fig. 4 Hardness profile, HRC

The ramp function of the loading force acting on the joint was transmitted by the entire surface of the sleeve. The joint underwent elastic deformation under the load up to 30 kN. Further increase in the loading force led to an onset of plastic deformation.

The numerical model of the joint will be used for further optimisation of the joint's shape in the future in order to increase its load-carrying capacity and to improve the stability of the entire structure.

6. CONCLUSION

The experiment consisted in designing and making a joint of a high-strength 50 mm diameter tube with the wall thickness of 3 mm and a sleeve. The explosive PENT in the amount of 0.97 g and water as the forming medium were used for the detonation. Forming was carried out without any tools. The load-carrying capacity of the joint was measured by means of a compression test of load-carrying capacity. The joint showed a load-bearing capacity of 30 kN but resisted the load up to 60 kN. This magnitude of load did not cause a full destruction either, as stable plastic deformation occurred with the extension of about 20 mm. The shapes of surfaces of the joint will be modified with the aid of FEM analysis and the strength level will be optimized with regard to requirements on the structure.

7. ACKNOWLEDGEMENTS

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