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Measurement and numerical analyses of residual stress distribution near weld joint

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Abstract

The aim of this paper is experimental X-ray verification of residual stresses in high strength steel materials after welding and numerical approximation of all stress components on the surface of the specimen. Welding of plates with square notch without thermal preprocessing or postprocessing can cause normal and tangential stresses in basic material. These stress functions will be evaluated near weld joint. The following numerical analyses can show the type and the size of loadings that can be transferred with this type of joined constructions.

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1. Introduction

Constructions with high strength steel elements are not so often in use, even though their outstanding mechanical properties. Large strength values are achieved with some thermal modifications of the base material. The fine grain structure and low carbon content make good expectations for welding these low alloy steel materials. High strength, toughness and fatigue resistance designate constructions made of high strength steel to be lightweight [1]. The reduction of the low alloy steel grade thickness brings more simplification into the welding process. Further positive possibilities include saving in the form of lower energy consumption, refined mechanical properties and also safety.

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The high strength steel grades have a low carbon equivalent value. The Parameter Crack Measurement (PCM) formula, which was especially developed for low carbon steels with content of carbon under 0.11 % shows that the carbon equivalent value is under 0.25.

It is not necessary to preheat or postheat steels with such a low carbon equivalent, especially steel grades with brand name like Domex, Amstrong Ultra and others. However, in the Heat-Affected Zone (HAZ) softening can occur in the microstructure. This is typical for rolled steel grades with yield strength over 500 MPa with thermomechanical processing. Of course, like in other cases the same goes for low alloy steel grades and the fact that softening and the width of the zone increases with heat input during the weld process. In cause of that it is way better to make a limit for the welding energy. Maximal permissible value is 1.5 kJ/cm per mm of thickness. Good mechanical properties are so assured.

Still there are zones with residual stresses in the HAZ, which can in small cross-sections cause increase of the possibility of a small crack occurrence caused by dynamic loading. These residual stresses can be measured in laboratory tests or predicted by FEM analysis. Both types of capitalizing residual stresses results are demanding on time and knowledge. FEM analysis requires also some experiments with operations like ferrous metallurgy and real welding for correct input data [3].

2. Residual stress

On the base of PROTO Manufacturing Company sources, the residual stress can be defined as “the stress resident inside a component or structure after all applied forces have been removed”. By pushing the material together, the compressive residual stress rises up. On the other hand, the tensile residual stress is created by pulling the material apart. In mathematic perspective, the compressive stress is seen as negative value and tensile stress as positive value. Normal stress is stress that acts perpendicular to the face of a material. Shear stress is stress that acts parallel to the face of a material. It is known total 6 independent stresses at any point inside a material. The stresses are represented by σ_i, where “*i*” is the direction that the stress is acting in. Than the shear stresses τ_{ij}, where “*j*” represents a face on which the stress is acting on and the “*i*” represents again the direction that the stress is acting in.

Residual stresses are created after plastic deformation. It is caused by applied mechanical loads, thermal loads and phase changes. If there are applied some mechanical and/or thermal processes to a component during service, it may also bring the effect of residual stress state [4, 5].

Knowledge of the value of the residual element of stress is consequential to correctly determine the real loads actuating on a component. In principle, compressive residual stress nearly the surface of a component is useful. There is trend of increasing of the fatigue strength and fatigue life of the component. There is also trend to slow propagation of cracks such as stress corrosion cracking and hydrogen induced cracking. But not all types of residual stresses are increasing some of the characteristics of the material or component. For example, tensile residual stress in the surface is in major cases unwanted, because it decreases fatigue strength and fatigue life. It also increases crack propagation and lowers resistance to environmentally assisted cracking [6].

2.1. Types of residual stresses

Knowledge of the residual stress helps to specify the scale of its expansion in the material. Microstresses rise only inside or between the grains. The summation of these 3 types of stresses gives the total residual stress [2, 8]:

- Macrostresses – will rise inside of the material, between grains and will appear on long distances.
- Microstresses – if there are differences in the microstructure of a material. Will rise inside of the material, between grains and will appear on short distances around the size of the grain. Can rise in single-phase materials and also in multi-phase materials. In the first case it is caused by the anisotropic behavior of individual grains. In the second case it is caused by the presence of different phases.
- Stresses without specific name – will rise inside of the material and is caused by crystal imperfections within the grain.