IOP Conf. Series: Materials Science and Engineering **286** (2017) 012016 doi:10.1088/1757-899X/286/1/012016

The nature of elastoplastic transition in low-carbon steel samples with and without welds

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Abstract. This paper describes the influence of a weld on elastoplastic transition in low-carbon steels. Depending on the level of internal stresses in the zone of the weld, the formation of Chernov-Lüders bands can occur either exactly in the weld or near it. In the second case, the influence of the weld is detected only when the front of the Chernov-Lüders band reaches it. In both cases, the features of kinetics for the fronts of the Chernov-Lüders bands are caused by the structural and phase inhomogeneity of a heat-affected zone and deposited metal.

1. Introduction

Strength and fracture are the most important characteristics of steels. To select a material for a product it is necessary to consider the material strength, since it determines whether it will resist loads for the required time before the material is fractured, and steels show the highest strength among materials. Another important quality is the availability of material. In this connection, the most common steels used to produce engineering constructions are low-carbon high-grade or low- grade steels. Engineering constructions consist of many elements. These elements can be joined by welds, the strength of which differs from the strength of material, most often toward a lower level. Thus, it is necessary to know the behavior of the base material under loading, as well as the behavior of material in the place of welded joints. The parameters defined as permissible for this structure should be used within elastoplastic transition range at the junction of elements.

Elastoplastic transition in structural low-carbon steels consists of the stages such as microplasticity, during which there are elastic strains and processes leading to irreversible deformation; a yield drop and a yield plateau corresponding to the growth of the Chernov-Lüders band (CLB) through the cross section and its further distribution along the sample [1]. These processes lead to the accumulation of strain in the sample up to 3.5%. This transition ends after the material passes from an elastic stress state to a plastic strain state.

Studying the behavior of material, that is the movement of CLB fronts in the basic material and in the material of welded joints, allows us to determine the limits of permissible stresses and strains for the engineering constructions consisting of these materials.

2. Methods and materials

The most widely used material in engineering constructions is low-alloy high-grade steel (09G2S) that was chosen to be the object of the study. Specimens of the dog-bone shape with a working part size of 2 × 6 × 40 mm were prepared from the 250 × 250 × 5 mm butt-welded plates, which were subjected to milling and mechanical grinding. In this case, the weld was located in the middle of the working section and perpendicular to the tension axis of the sample. The width of the deposited metal was about 5 mm, and the heat-affected zone surrounding this one was 1.5 mm. To observe CLB fronts, it is necessary to ensure that the working surface of the sample is the diffusively-reflecting one and the samples are subjected to deep etching in a 12% alcohol solution of nitric acid.

A testing machine Walter+Bai AG LFM-125 was used for mechanical uniaxial tensile testing of the samples. During the test, a deformation diagram was recorded in digital form. After analyzing the tests, it can be concluded that the deformation rate of the sample is $8.3 \cdot 10^{-5}$ s^{-1} at the speed of the movable (top) testing machine grip of 0.2 mm/min. The method of digital statistical speckle photography was used during the tensile process to obtain an "in situ" record for the centers of deformation localization [2]. The use of this method leads to the fact that these centers of deformation localization appear as dark contrast bands superimposed on the speckle images of the deformed samples and, in fact, represent the boundaries or fronts of CLB. Comparison of the deformation diagram with the distribution of the deformation localization centers showed that the stages of the tensile curve were in a good agreement with the behavior of the CLB fronts.

3. Results and discussion

The propagation of CLBs in the homogeneous low-carbon steel samples can be called stochastic. However, numerous uniaxial tensile tests show that two CLBs formed often near both testing machine grips [2, 3]. Moreover, each band has two moving fronts diverging in different directions, one of which soon reaches the edge of the working section and then stops. The remaining fronts move towards each other at a constant velocity, at the same time, bands expansion rate remains the constants. This is because the velocity of the CLB front propagation directly depends on the expansion rate of the plastically deformed part in the sample [4]:

$$\sum_{i=1}^{N} \left| V_f^{(i)} \right| = \left(V_f \right) = const, \tag{1}$$

In this formula, $\boldsymbol{N}$ is the number of simultaneously moving CLB fronts, $\boldsymbol{V_f^{(i)}}$ is the propagation velocity of the i-th CLB front, and $\boldsymbol{(V_f)}$ is the expansion rate of the plastically deformed part in the sample, equal to approximately 0.16 mm/s for this case. Thus, if one of the moving CLB fronts stops, the velocity of the remaining one is increases by the velocity of the stopped front. These relations are valid both for any time moment and for any number of moving fronts.

The samples with a weld have a different picture of the CLB formation. The presence of a weld in samples has a significant effect on the formation or distribution of CLBs. Depending on the process, internal stresses in heat-affected zones can be higher or lower compared with the basic metal. Since the stresses in heat-affected zones are higher than in the base metal, the formation of CLB occurs in the decarbonized zone of a weld [5]. In this case, the CLB formation in a weld differs from the CLB formation in the basic metal. If, in the latter case, a CLB grows from the one edge of the working section of the sample to the other one with clear boundaries, then for the first case the picture is different. In the beginning, a large number of small centers of deformation form in the zone of deposited metal, and then a CLB forms during the next 3-8 seconds. This CLB occupies the entire area of deposited metal, but does not have clearly observed fronts. The moving CLB fronts form only in the heat-affected zones of the weld during the first minute after the start of loading. Further propagation of the CLB fronts takes place according to the well-known scenario observed in the samples without a weld [2-4]. The velocity of the fronts is approximately equal to 100-150 μm/s and does not differ much from the velocities in homogeneous samples.

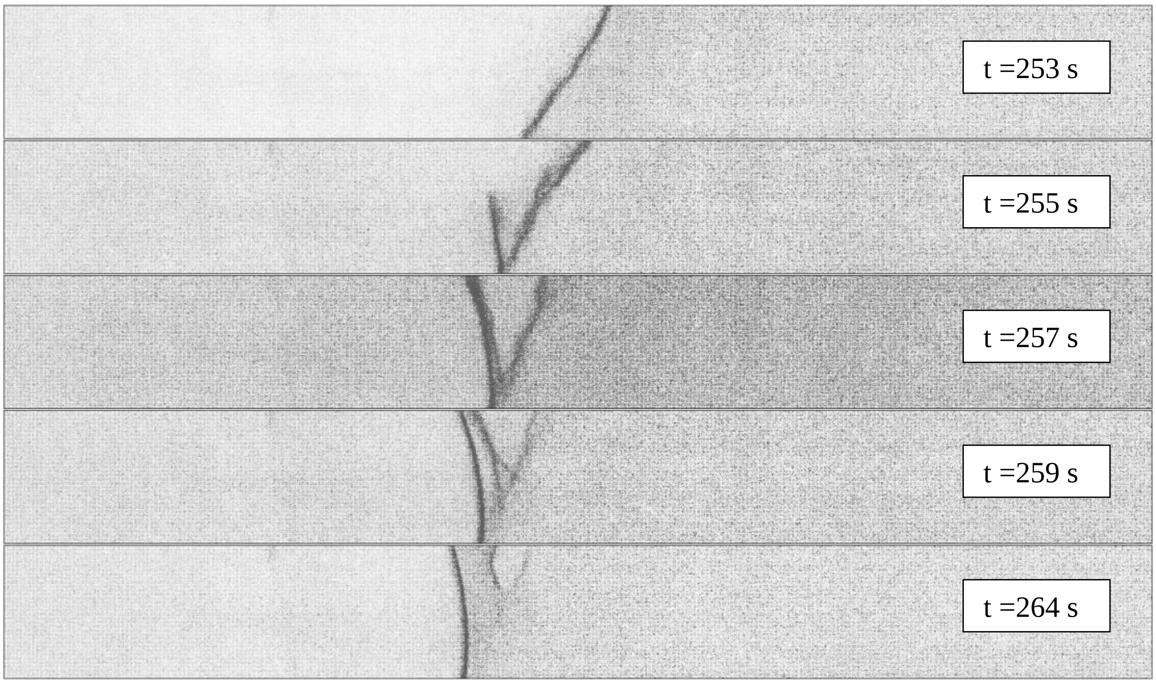

Figure 1. Chernov-Lüders bands behavior in welded joint zones.

In the other case, if the internal stresses in heat-affected zones are lower than in the basic metal [5], another scenario of elastoplastic transition takes place and the presence of a weld has an effect on the CLB distribution. A CLB forms outside the zone of deposited metal, as in the case for the homogeneous sample, near one of the testing machine grips. When one of the fronts reaches the edge of the working section and stops, the velocity of another one increases according to formula (1), and the front continues propagation along the sample. Having reached the boundary of the weld, the CLB front stops and becomes the source of a new CLB nucleation directly in the deposited metal. In this case, the CLB forms in the deposited metal two times faster than in the homogeneous sample under normal conditions [2]. The time required for this process is approximately 3 seconds, and the speed is higher than 2 mm/s. The further deformation of the sample occurs directly in the weld: while the CLB is distributed in the zone of deposited metal, the CLB front remains stationary outside this zone. At the same time, the CLB front moves in the deposited metal at a velocity of about 0.5 mm/s and exceeds the velocity of CLB front propagation in the base material (Figure 1). At the time when the deposited metal is completely deformed, and the CLB front located in it disappears, the stationary CLB front in the heat-affected zone starts moving and continues to be propagated in the base metal with velocity is about 100 μm/s that corresponds to the velocity of front propagation in a homogeneous metal.

4. Conclusions

The existence of a weld in a sample determines the CLB formation. If stress in a heat-affected zone is higher than in the basic metal, a CLB will form directly in the weld. If stress in a heat-affected zone is higher than in the basic metal, a CLB will form outside the area of deposited metal. However, since the weld's area has a large structural and phase inhomogeneity, regardless of where a CLB is formed, it strongly influences on the behavior of deformation. In this case, the difference in the structure of materials leads to the fact that the kinetics of CLB fronts in the deposited and base metal are substantially different, and the velocity of fronts there can differ by an order of magnitude. In addition, a CLB front can stop at the boundaries of zones with a different structural and phase state and become the source for the formation of one or even several CLBs. At the same time, the critical formation processes of moving CLB fronts are localized in heat-affected zones.

Acknowledgments

The work was carried out within the framework of the Program of Fundamental Scientific Research Russian State academies of sciences for 2013-2020.

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