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RESEARCH OF THE PLASTIC DEFORMATION LOCALIZATION OF BIMETAL

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The aim of this contribution was to study the localization of the plastic deformation of bimetal based on a low-carbon steel A 283 Grade C and austenitic stainless steel 301 AISI. The images of the localized zone plastic deformation upon the uniaxial tension have been obtained with using digital image correlation method (DIC). The stress-strain curves are found to show all the plastic flow stages: yield plateau, linear and parabolic work hardening stages and the prefracture stage would occur for the respective values of the exponent from the Ludwik-Holomon equation. The main parameters of plastic flow localization at various stages of the deformation hardening have been determined in bimetal.

Key words: bimetal, localization of the plastic deformation, DIC, tensile test, strain

INTRODUCTION

Scientists are continually searching to find new material with better properties for industrial application. [1] Ones new multi-layer materials are identified, machining and joining processes for them are also developed [1-3]. Bimetal belong to these materials, which are composed of two metals and alloys.

The most important advantage is that cladding steel no only saves cost more than similar steels made entirely of cladding materials, but also provides other functions including good mechanical strength, good resistance to heat and corrosion. Therefore, it is widely used in petroleum, chemical, medicine, and nuclear industries [4-6].

In this study, bimetal consisted of austenitic stainless steel 301 AISI and low-carbon steel A 283 Grade. Stainless steel has an excellent corrosion resistance and stability in gaseous and aqueous environment and an excellent specific strength compared to low carbon steel. Carbon steel has a good strength and an excellent cost advantage over stainless steel, but less environmental stability and corrosion resistance. Recently, the efforts to develop mechanically reliable stainless steel/ carbon steel bimetal have increased considerably driven by the need for materials with excellent corrosion resistance, good environmental stability, high specific strength and low production cost [7].

Multilayer metals exposed to extensive plastic deformation during operation. A limited number of investigations are devoted to deformation behaviors of bimetal. Currently, heterogeneity of plastic deformation at macro-, meso- and microscopic scale have been identified and studied for a wide range of pure metals and alloys [8-10].At the macroscopic level the plastic deformation will exhibit an inhomogeneous localization behavior from yield stress to failure. Various forms of this plastic deformation localization can be considered as different type of auto waves that depend on the strain hardening law taking place at the stage. According to early works [11], focusing on the auto waves approach for the description of the localized plastic deformation of FCC, BCC and HCP of metals and alloys, are gathered with the use of the ALMEC-tv measuring complex for digital recording of speckle images, above-mentioned methods are proposed to study plastic flow localization in bimetals.

EXPERIMENTAL

Materials and fabrications

The investigations were performed for anticorrosive bimetal are based on joining dissimilar metals: low-carbon steel a 283 grade c and austenitic stainless steel 301 AISI. This two layer composite was produced via pouring followed by rolling on a required thinness of 8 mm. The thickness of the cladding layer was 0,6 mm. Pouring liquid metal onto a solid plate placed in the mold is frequently used to fabricate various bimetals.

Response measurements

Previously prepared in the form of dog bones, the specimens with dimensions of the working part 40 ×8×2 have been tensiled with testing machine LFM-125, at

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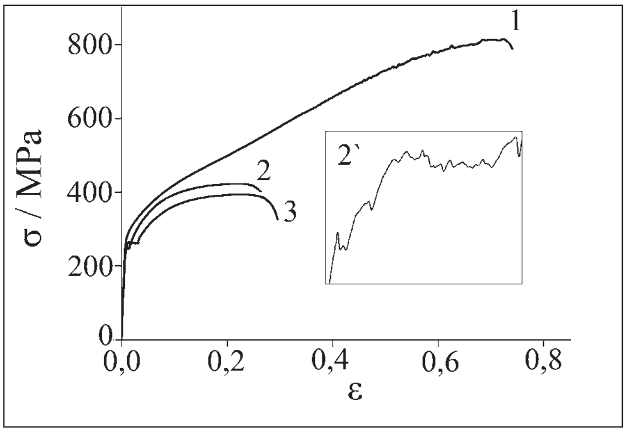

Figure 1 Loading curves: 1 - A 283 Grade C; 2 - bimetal; 3 – 321 AISI; 2′ is the yield surface of curve 2 for the bimetal

300 K with a rate of 6,67×10^{-5} s^{-1}mm/min. The stress-strain curve was obtained simultaneously with measuring the fields of the displacement vectors r(x, y) with using of the universal measuring complex for digital recording of speckle images ALMEC-tv based on DIC method. This enabled to measure of displacement vector fields for the sample surface. The measurements were performed over the entire plastic flow process from tensile yield point to fracture.

Use of this method makes it possible to determine the main characteristics of propagation of the zone of localized plastic deformation such as the spatial and temporal T period of the process.

RESULT AND DISCUSSION

As a result of tensile test, loading curves of flat samples of bimetal, and the samples equal in size made separately from steels 321 AISI and A 283 Grade C are presented in Figure 1.

They cover the areas of elastic and large deformations, and the area of fracture. The bimetal curve after the yield point in the area of large deformations is located between the curves for its components (20 samples from each material were tested). On the loading curves for 321 AISI and the bimetal, the pronounced tooth and the yield plateau are visible, on which the oscillations of the deforming stress are noticeable (Figure 1). The presence of a cladding layer of stainless steel leads to a reduction in the duration of the yield plateau, an increase in the strength limit, and a decrease in the ductility of the base metal (321 AISI).

The plastic flow curves is attributed to the general diagrams described by the Lüdwig equation:

$$\sigma(\varepsilon) = \sigma_y + \theta\varepsilon^n \quad (1)$$

where θ is the coefficient of deformation hardening and n is the exponent of deformation hardening. The strain exponent n has different values in different portions of the stress-strain curve and changes in a stepwise manner depending on the degree of strain. Particular constant values of n and θ correspond to each of the deformation stages.

An analysis of the loading curve of bimetal shows that the specificity of this curve is the occurrence of yield plateau and yield drop (Figure 1). The extent of yield plateau with yield drop is 1, 1 %, that is conditioned by the propagation of the Lüders band (LB) in the area of the base material (A 283 Grade C).

The analysis of the stages in the loading diagrams of bimetal specimens from the work hardening coefficient $\theta = d\sigma / d\varepsilon$ and the constant value n (here is the exponent of deformation hardening in the Lüdwik equation) reveal the following peculiarities of the deformation curves for the material studied. The transition segment from the elastic part to the plastic flow is supervened by the yield plateau that changed by the linear-hardening stage with the total deformation of ε_{tot} = 0,003 % ÷ 0,005 %. The Taylor parabolic work-hardening stage with the constant n = 1/2 and the total deformation of ε_{tot} = 0,012 % ÷ 0,020 % comes after, and, finally, there is the pre-fracture stage with the constant n ~ 0,3 and total deformation of ε_{tot} = 0,024 % ÷ 0,029 %.

Plastic deformation of the composite emerges from the Lüders band interface in the bimetal. However, the stainless steel 301 AISI high-strength cladding metal prevents the propagation of the Lüders band with the constant velocity from the clamp of the machine as the basic stress concentrator. This results in the abrupt movement of the initial band with the origin and propagation of other Lüders bands (LB) through the specimen section from the cladding metal – basic metal interface (Figure 2).

The emergence of the stress concentrators is caused by the bending moments that arise upon plastic deformation of the bimetal. The propagation of the local elongations on the yield plateau is the relay propagation

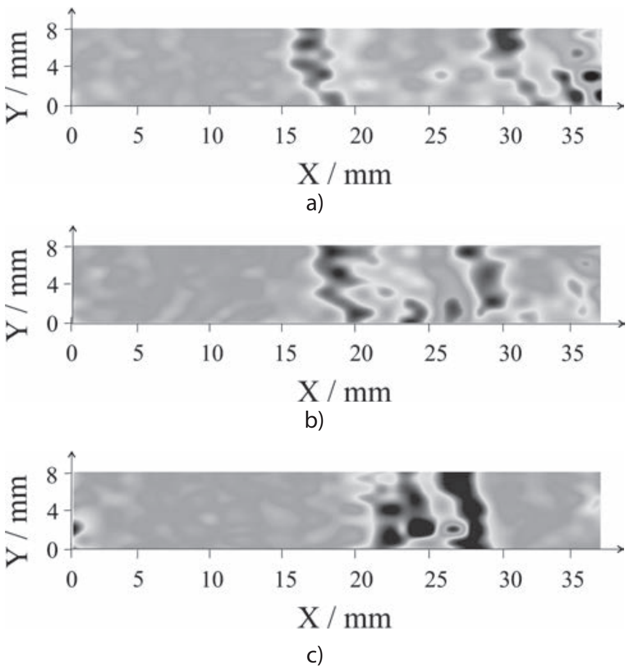

Figure 2 Visualization of Lüders band propagation through the bimetal length at the total deformation of (a) 0,006, (b) 0,008, (c) 0,012

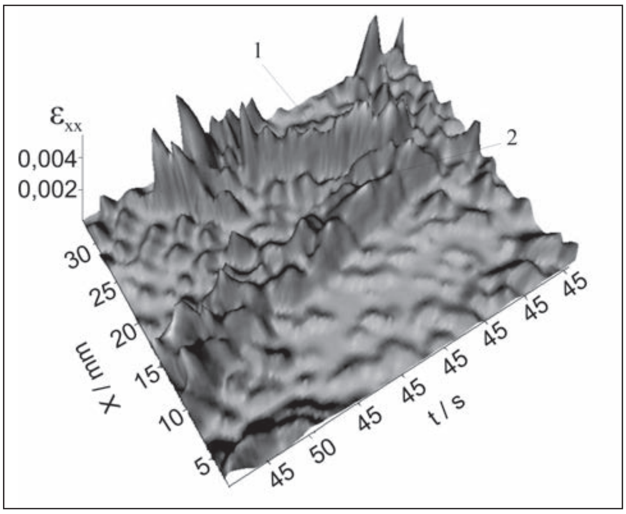

Figure 3 Visualization of kinetic plot X(t) of strain localization zone along sample axis as functions of time at yield plateau

of the Lüders band fronts emerging near the clamps and at the opposite interfaces. The Lüders fronts move and vanish when meeting each other on the yield plateau (Figure 2).

To study the kinetics of the evolution of the macrolocalization zones, we used the representation of the positions of local deformation zones X, in the sample as functions of strains ε_{xx} or time t (at active tension, $\varepsilon \sim t$ (Figure 2); the coordinate X is counted off from the immobile grips of the tensile machine). In [11], it has been shown that the use of this method for the distributions with a time–spatial periodicity (wave distributions) makes it possible to determine the spatial and temporal periods of the process, as well as the velocities of the motion of the deformation zones $V = dX/dt$.

It was found out that when the LB starts, its two fronts move in the main layer of 321 AISI with different velocities $V_1 = 0{,}8 \cdot 10^{-4}$ m/s and $V_2 = 2{,}3 \cdot 10^{-4}$ m/s (Figure 3).

The sequence of the plastic deformation localization zones is found at the linear deformation strengthening with the spatial period $\lambda = 4$ mm and their propagation velocity $V_{aw} = 6 \cdot 10^{-5}$ m/s.

The parabolic reveals plastic flow localization in the form of a stationary system of the plastic flow centers through the specimen length with the distance $\lambda = 4$ mm between them (Figure 4a).

At the prefracture stage, the immobile zones of plastic strain localization started moving consistently with a tendency to merge into a high-amplitude focus of localized straining (Figure 4b), where a neck-like narrowing of the sample cross section was formed (Figure 5). This maximum forms at the place of occurring damage. The peculiarity of damage of the bimetal is related to the heterogeneity of plastic deformation in the intermediate layer of the metal, where the stress concentrator as a trihedral prism is formed on microlevel. Fragmentation of the specimen determines the fracture pattern of bimetal composite. Two macro bands of localized plastic

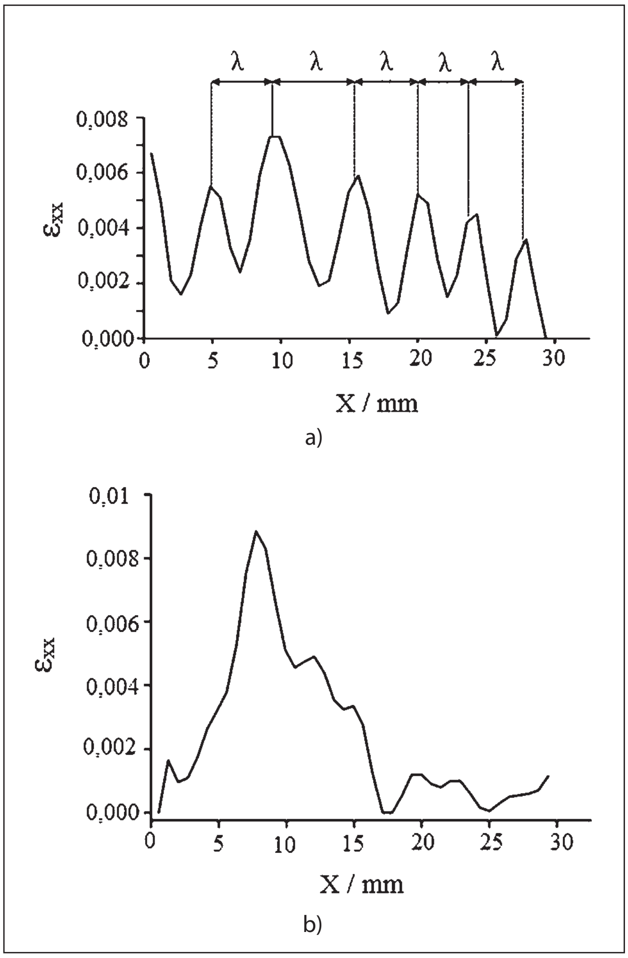

Figure 4 The local elongation ε_{xx} along the axis of extension during (a) - parabolic strain hardening; (b) - prefracture stage

deformation are formed at the stage of the shoulder effect in the area of stress macro concentrator. They propagate along conjugated directions of maximum shear stress across the whole section of the sample, forming trihedral prisms on the macro level on the bond interface of the bimetal. The cracks are nucleated in the area of parent metal at the trihedral prism tip, gradually merged passing across the whole section of the metal sample (Figure 5).

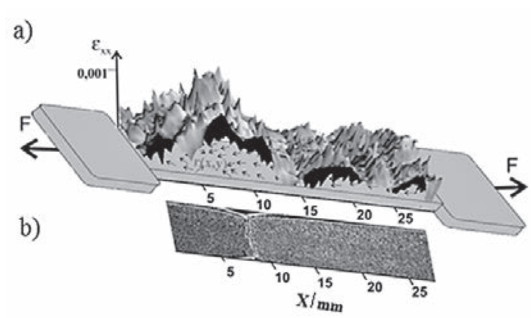

Figure 5 The picture of localized zones evolution for parabolic work hardening and prefracture stages, under deformation 0,022 % – (a); bimetal fracture patterns and distribution of local extensions at the prefracture stage under deformation 0,024 %– (b)

CONCLUSION

The characterization of the stainless steel – low-carbon steel composite upon uniaxial tension has enabled us to reveal the following features of the deformation of plastic bimetals. The zones of localized plastic deformation are formed and evolved during plastic flow in the basic metal. The cladding layer in the material prevents the propagation of the Lüders bands with a constant velocity from the machine clamp as the basic stress concentrator. The bands that have emerged move abruptly with the other Lüders bands from the cladding metal – basic metal inner interfaces and pass through the whole cross-section of the specimen. Fragmentation and destruction of the bimetal are caused by the formation of the stress concentrators at the cladding metal – basic metal inner interface.

The localization behavior of plastic deformation of bimetal is its most salient feature. By constant-rate tensile loading, space-time periodic structures, which are called now patterns, will emerge in the deforming sample from yield limit to failure of material. A total of four localized plasticity patterns have been observed experimentally for all studied materials which differ in chemical and phase composition, crystal lattice type (FCC, BCC or HCP), grain size and deformation mechanism [9].

Acknowledgments

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Note: The response for English language is YU.V Stankina the translation professional of National Research Tomsk State University «TSU»