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Conditions improving of laser heating for forming of materials with a ferritic-martensitic structure

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Abstract. High-strength dual phase ferritic-martensitic steels with a controlled amount of martensite have the most favorable combination of durability and plasticity compared to other low-alloy steels. The possibility of conditions improving of laser heating for forming sheet materials with a ferritic-martensitic structure has been determined. It is shown that the redistribution of the power density of the heat source allows this process to be performed without a significant local decrease in the profile thickness. A diffusion-cooled and high-frequency excited CO₂ laser ROFIN DC 010 with a maximum output power of 1000 W was used as the laser source. To redistribute the laser power density, a diffractive optical element (DOE) was used. The region of plastic deformation is characterized by a local decrease the thickness profile, while microcracks and a discontinuity of the metal weren't observed.

1. Introduction

Due to its extremely localized, concentrated energy input of focused laser radiation, laser material processing delivers a higher energy density as practically any other heat source to processed components. Thus, laser material treatment can be used not only for laser welding or cutting, but for modification of physical and mechanical properties of materials. In numerous articles, monographs and reference books [1-5] it is shown that such important characteristics of metallic materials, as tensile strength, fatigue strength and wear resistance are structurally-sensitive, i.e., can be controlled by proper changes of material structures due to laser processing. However, if questions in relation to selective laser modification of metallic materials are considered, most of the work so far was devoted to hardening, either by heat or deformation. While improving the structural condition of the material by annealing, a significant improvement in the plastic flow of the metal and the localization of the deformation can be realized [6-8].

Dual phase (DP) steels are steels with a ferritic basic structure, in which the martensitic phase has an island arrangement. These are characterized by a high tensile strength due to relatively hard martensitic phase and a low initial yield point due to the relatively soft ferritic phase [9]. Due to the good combination of strength and formability, DP steels offer the potential to improve the vehicle crash worthiness performance without increasing car body weight and have been recently used in new vehicles. However, the application of DP steels in many auto body and structural parts is still limited since many issues have to be investigated related to manufacturing formability, joining ability, and die



life [10-11]. The local laser annealing of plastic deformation areas provides an increase in the ultimate elongation, and a decrease in the minimum bend radius. These approaches are advisable to use also for local modification of DP steels [12-14]. The purpose of this study is to determine the possibility of conditions improving of laser heating for forming sheet materials with a ferritic-martensitic structure.

2. Results and Discussion

In Refs. [13, 14] conditions of laser heating for warm forming of materials with a ferritic-martensitic structure were revealed. The process of forming with laser heating specimens from DP 1000 steel with a thickness of 1.5 mm was studied. A fiber laser with a maximum output power of 1500 W was used. The beam was transformed with the use of a plano-convex lens and axicon to an elliptical ring, which was projected onto the surface at an angle of 45° .

Study of samples microstructure was performed with the use of a scanning electron microscope (SEM) TESCAN Vega SB. It was revealed fibrous structure of metal, formed during the manufacture of blanks rolling. It was determined that the thinning in the area of plastic deformation is unevenly distributed. Figure 1 shows a zone of maximum thinning. The minimum material thickness was 0.8 mm. Also the thinning was observed outside of this zone; however, the deformation here is not as intense. Along with the appearance of a significant difference in thickness, there is a probability of failure of the inner surface layer of material with the formation of microcracks (Figure 2) and / or surface tears.

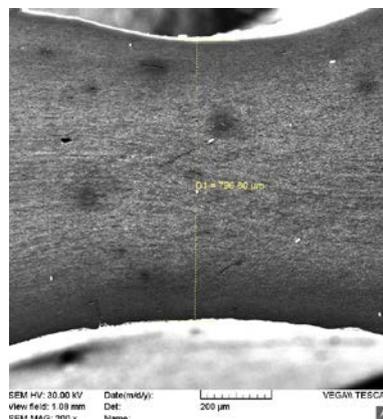


Figure 1. A zone of maximum thinning in the area of plastic deformation after forming of materials with a ferritic-martensitic structure.

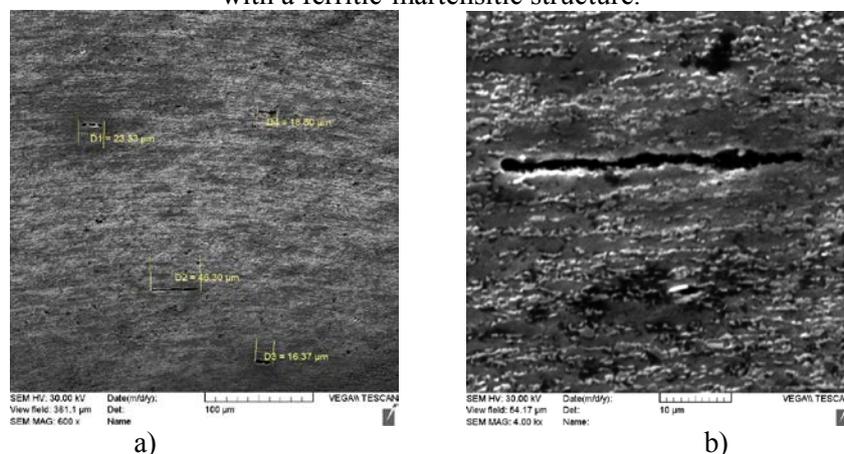


Figure 2. The formation of microcracks in the area of plastic deformation, SEM magnification: 600x (a), 4000x (b).

The deformation leads to a change in the shape of grains, which receive a shape elongated in the direction of deformation or the most intense flow of the metal, which is naturally expressed to a greater extent for steels with a high content of ferrite. Hardening of steel is achieved as a result of an

increase in the density of dislocations, the formation of a cellular substructure in the ferritic component. During plastic deformation, crushing and grinding of grains take place. The presence of fine-grained structure can lead to acceleration of the kinetics of recrystallization and austenitization during heat treatment. Due to the crushing and stretching of grains during the deformation process, the total surface of boundaries increases, blocks inside fragments decrease. Under the action of deformation, solid solutions decompose. Products of this decay also lead to hardening. Strong obstruction of slips by various defects leads to a decrease in the plasticity of the material. Along with this, there is a gradual accumulation of such defects, which lead to destruction.

The possibility of improving conditions of laser heating for forming sheet materials with a ferritic-martensitic structure was determined. Because forming is a process that occurs only at the expense of material thinning, a reduction of local thinning over a large processing area is desirable, including the central part in particular. Thus, it is possible to achieve a reduction of maximum thinning. A redistribution of the power density of the heat source allows this process to be performed without a significant local decrease in the profile thickness. A diffusion-cooled and high-frequency excited CO₂ laser ROFIN DC 010 with a maximum output power of 1000 W was used as the laser source. To redistribute the laser power density, a diffractive optical element (DOE) was used. Intensity distribution in the focal plane of this DOE was shown in Refs. [15, 16]. It is advisable to perform a uniform heating of the treatment area to a temperature close to the critical point, with a minimum duration of heating and exposure at the peak temperature in order to prevent softening.

The temperature in the tempering zone did not exceed the temperature at which austenite begins to form when heated (point of phase transition AC₁), but approached it. The material softening in this zone occurred due to the formation of ferrite and tempered martensite. The amount of tempered martensite depends on the temperature and the exposure time. Figure 3 shows the zone of maximum thinning of the metal material after such processing and forming a sample of steel DP 1000 with a thickness of 1.5 mm. The minimum material thickness observed after forming was 1.08 mm. Figure 4 shows an image of the microstructure, obtained with a SEM. The black matrix is ferrite, and the gray raised parts are martensite. In DP1000 steel, islands of martensite are dispersed in the ferrite matrix, which leads to greater strength with sufficient ductility and toughness. It is known that at the first stage the ferrite is deformed, then the joint deformation of the ferrite and martensite occurs, and at the final stage the deformation of martensite is possible. The microstructure presents alternating layers of ferrite and martensite, elongated in the direction of principal deformation. Due to the nucleation and growth of austenite, as well as the further formation of martensite at grain boundaries during cooling, ferrite grains have a degenerated morphology.

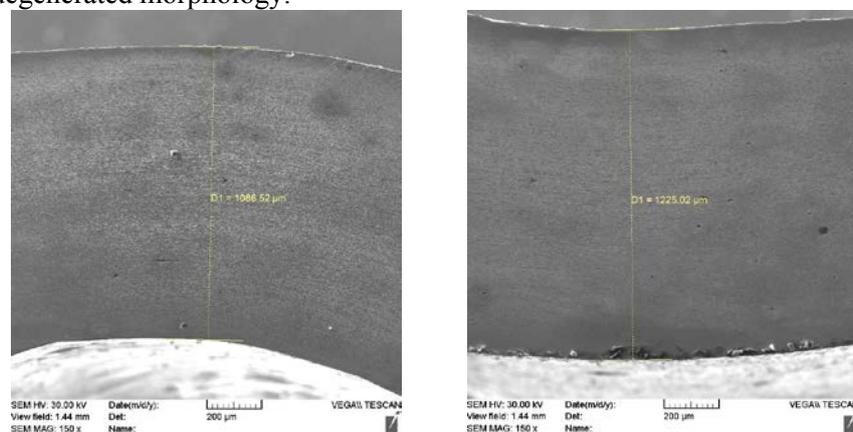


Figure 3. SEM images of zone of maximum thinning of the metal material after laser treatment with DOE and forming a sample of steel DP 1000.

As a rule, dual phase steels are defined as consisting of a ferritic matrix with the presence of dispersed martensite islands. But due to a high volume fraction of martensite in DP1000 steel, almost all ferrite encompasses martensite, which forms a contiguous microstructure that is better described not as an island microstructure, but as a network-like microstructure [17]. Sulphide inclusions of

different sizes elongated in the rolling direction were observed between grains. The region of plastic deformation is characterized by a local decrease the thickness profile, while microcracks and a discontinuity of the metal weren't observed.

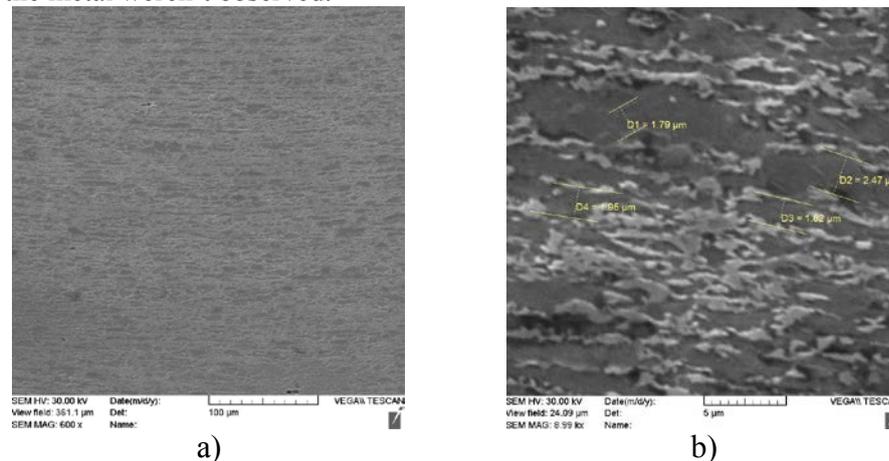


Figure 4. SEM images of the microstructure, SEM magnification: 600x (a), 9000x (b).

Features of the behaviour of dual phase steels as composite materials are determined by the difference in strength characteristics of martensite and ferrite, which can be reduced in the process of laser annealing [18]. It becomes necessary to decrease the dislocation density prior in ferrite and to perform a second softening stage at the heat affected zone, at which a decrease of martensite fraction and the appearance of bainite and martensite-austenite constituents occurs [17, 19]. Some residual austenite also remains in the microstructure. Compared with fully hardened steels, singularities of annealing of dual phase steels are caused not only by the presence of ferrite oversaturated with interstitial atoms, but also by residual stresses as a result of local martensitic austenite transformation, increased dislocation density in ferrite zones near martensite boundaries, small sizes of residual austenite, as well as heterogeneity of precipitates of special carbides in the volume of the hardened steel. It should be noted that dual phase ferritic-martensitic steels, which are materials for the manufacture of parts by cold working or methods the plastic deformation of metals below the recrystallization temperature, do not show a tendency to aging during long-term storage at temperatures near room temperature. With that, hardening of parts from dual phase steels provides an opportunity to increase their performance characteristics which is in some cases necessary. In identifying rational heat treatment conditions from a dual phase area during laser heating, factors affecting the austenization kinetics, as well as preferred sites of austenite nucleation and its morphology, should be taken into account. These factors are the initial structure, the composition of the steel, the number and size of dispersed particles, etc. At the same time, the choice of specific laser processing modes should ensure not only obtaining a predetermined structure, but also its minimum sensitivity to inevitable fluctuations of process parameters.

3. Conclusions

The process of forming with laser heating specimens from DP 1000 steel with a thickness of 1.5 mm was studied. After a laser heating and forming process, specimens showed a fibrous metal structure. It was determined that the thinning in the zone of plastic deformation is unevenly distributed. The minimum material thickness was 0.8 mm. Additionally, thinning was observed outside of this zone; however, the deformation here is not as intense. Along with the appearance of a significant difference in the thickness, there is a probability of failure of the inner surface layer of material with the formation of microcracks and / or surface tears.

Possible conditions for an improving of laser heating for forming sheet materials with a ferritic-martensitic structure have been determined. To avoid unwanted shape changes, is advisable to use diffractive optical elements (DOE), which redistribute the power density of a laser beam. A diffusion-cooled and high-frequency excited CO₂ laser ROFIN DC 010 with a maximum output power of 1000

W was used as the laser source for further research. To redistribute the laser power density, a diffractive optical element was used. It is shown that the redistribution of the power density of the heat source allows this process to be performed without a significant local decrease in the profile thickness. Study of the microstructure allowed revealing of fibrous metal structures, formed during the manufacture of blanks by rolling. The region of plastic deformation is characterized by a local decrease the thickness profile, while microcracks and a discontinuity of the metal weren't observed.

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