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THE EFFECT OF THE ASYMMETRICAL ROLLING PROCESS ON STRUCTURAL CHANGES IN HOT-ROLLED BIMETAL SHEETS

The paper presents research results on the selection of parameters for the asymmetric rolling process of bimetallic plates 10CrMo9-10 + X2CrNiMo17-12-2. They consisted in determining the optimum parameters of the process, which would be ensured to obtain straight bands. Such deformation method introduces in the band the deformations resulting from shear stress, which affect changes in the microstructure. But their effect on the structure is more complicated than in the case of homogeneous materials. It has been shown that the introduction of asymmetric conditions into the rolling process results in greater grain refinement in the so-called hard layer. There was no negative effect on the structural changes in the soft layer observed.

Keywords: asymmetric rolling, microstructure, plastic deformation

1. Introduction

Bimetallic products, which includes metal sheets, strips, wires or rods, are increasingly used in many branches of industry [1-8]. This is mainly due to their properties resulting from the combination of two materials, in which one is characterized, for example, by high corrosion resistance, electrical conductivity, etc., while the other mainly meets strength requirements.

The manufacturing process of this type of product is complicated and difficult to develop. The problems concerns both: the joining process itself and the subsequent rolling process. Not all joining methods allows to merging the specific materials in pair or the quality of the obtained connection is insufficient because for example the shear strength of the joint is too low, which disqualifies the final product. In the rolling process of bimetal products, the most common problem is the selection of appropriate conditions for the rolling process. This occur especially in the case of multilayer sheets rolling, because a parameters deviation results in a product characterized by a shape incompatibility (bending of the band) [8]. Often bending of bimetallic plates due to uneven lengthening of layers in the initial culverts makes it impossible to continue the rolling due to the inability to capture the bands in the next rolling pass. There are known in the literature [8,9] methods to determine the appropriate conditions for the bimetallic plate rolling process, although still many problems appears with their determination for new material pairs.

The vast majority of two-layer flat products which are rolled in the traditional way are characterized by the incompatibility of the shape (bending) caused by uneven deformation of individual layers. The bending value is influenced by many factors, including differences in deformation resistance of bimetal component materials or the conditions of rolling. For this reason, the rolling process of bimetallic sheets is in assumption asymmetrical. Asymmetry results from differences in the properties of bimetal materials. Good control of the rolling process parameters through the appropriate selection of roll diameters or their rotation velocity can minimized or even removed the effect of the bent strip after leaving the rolling mill. It was also observed that the introduction of asymmetry through the occurrence of form deformations influences the fragmentation of the homogeneous products microstructure. In the case of the asymmetric rolling process of bimetal plates guaranteeing a simple band, there are also form deformations that affect changes in the microstructure, but their effect on the structure is more complicated than in the case of homogeneous products.

2. Asymmetrical rolling process of bimetallic plates

The firsts works concerning the use of asymmetry in the rolling processes were published in the 1940s [13]. Initially, it was used to improve the technological aspects of the rolling process of particularly flat bimetal products. The necessity of its introduction into the rolling process of double-layer sheets resulted mainly from differences in the properties of bimetal materials. As a result, the vast majority of flat two-layer products deform unevenly in the so-called symmetrical rolling process,

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realized with uniform speeds of work rolls. As effect of this unevenness is obtaining a bent band after leaving the rolling gap. The value of this bending is influenced by many factors, among others differences in deformation resistance of bimetal component materials or the conditions of rolling. In order to obtain a straight double-layer sheet, the asymmetry of peripheral speed of working rolls was used in the works [7-9]. In those works was described the formula below:

$$a_v = \frac{V_g}{V_d} \tag{1}$$

where: V_g, V_d – peripheral velocity of the upper and lower rollers.

At the turn of the 20th and 21st centuries, the first mention was made of the use of asymmetry to shape the structure of homogeneous materials [12]. Nowadays there are relatively many work concerning modeling of structural and geometry changes [10,11,14-18]. In most cases, however, they concern homogeneous materials. Therefore, in this work, the impact asymmetry of working rolls peripheral velocity, during the rolling of bimetallic plates, on the structural changes has been analyzed. The comparative analysis of microstructure was made after the bimetallic sheet production, and after symmetrical and asymmetrical rolling process (Fig. 1).

On the basis of numerous works [7-9], it was shown that the introduced asymmetry of peripheral working rolls velocity allows obtaining even flow of both bimetal layers in the plane of exit from the roll gap, and thus the possibility of such correction of the band shape to obtain a final product meeting standards. Authors of works related to asymmetric rolling focus mainly on the band shape controlling and lowering the energy and power parameters. Generally the aspect of structural and microstructural changes during such process is ignored or insufficiently described. This aspect is very important especially for bimetallic material like bimetallic plates.

3. The purpose and scope of research

The purpose of this work was to determine the effect of asymmetric rolling parameters on microstructural changes occurring in the components, layers of bimetal sheets. The comparative analysis was made for the rolling process at uniform rollers speeds and at different speeds of rollers for which a straight bimetallic sheet was obtained. The Forge 3D software which is based on the finite element method was used during numerical determination of the optimum value of rollers speeds. On the basis of computer simulations, optimal conditions for bimetallic plates composed of 10CrMo9-10 steel and X2CrNiMo17-12-2 rolling were determined.

The next step was to conduct the rolling process on a semi-industrial line of which the main element was the DUO 300 rolling mill (Fig. 2). The line is equipped with a measuring system allowing registration of power and energy parameters of the rolling process. The measurement was made directly by the force sensors and the rolling torque in an indirect way on the basis of signals received from frequency converters supplying the upper and lower drive engines. During the experimental investigations the metal pressure force on the roll was measured by two CL21 type force transducers in the 250 kN range, placed between the upper roller bearing covers and setting screws.

Experimental tests were made for bimetallic sheets composed of 10CrMo9-10 and X2CrNiMo17-12-2 steel with a thickness of 12 mm (where 8 mm was 10CrMo9-10 steel and 4 mm steel X2CrNiMo17-12-2) whose chemical composition is shown in Table 1. The choice of material was dictated by the fact that this type of bimetal is currently used in power plants, among others for boiler systems and elements exposed to flue gas. For many years, authors of this paper are conducting researches of multilayer materials and changes in the microstructure as a result of the applied plastic deformation. The analysis of literature showed

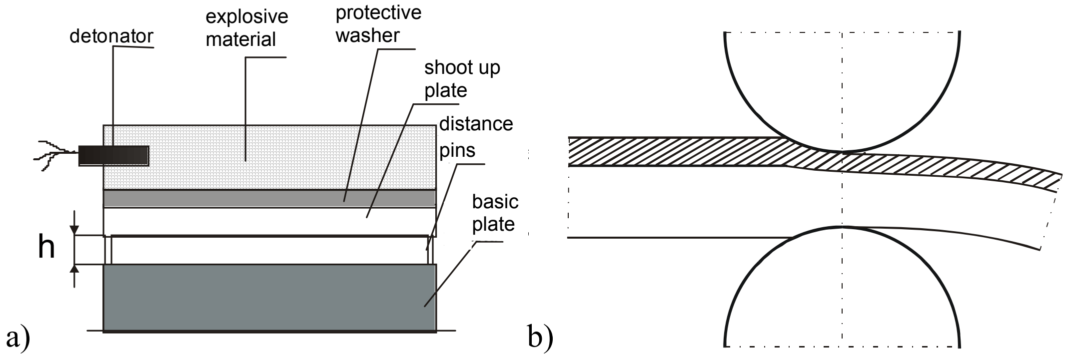

Fig. 1. Stages of production of bimetallic plates, a) combining by the method of explosive welding, b) scheme of asymmetrical rolling of bimetallic plates [7-9]

TABLE 1

Chemical composition of the tested materials 10CrMo9-10 and X2CrNiMo17-12-2

Material	**Chemical composition [% mass]**											
	C	**Mn**	**Cr**	**Mo**	**Ni**	**Al**	**Cu**	**Co**	**P**	**Si**	**S**	**Fe**
10CrMo9-10	0.12	0.52	2.0	0.91	—	0.03	—	—	0.01	0.35	0.01	Rest
X2CrNiMo17-12-2	0.03	2.0	16.61	2.0	10	—	0.34	0.25	0.04	0.75	0.01	Rest

Fig. 2. View the DUO-300 laboratory rolling mill

a gap in the area of knowledge related to asymmetric rolling of multi-layer products and changes of microstructure. Before rolling samples were heated in a chamber furnace to a temperature of about 1100°C for 20 minutes. After heating, samples were transported with a roller conveyor to the rolling mill. The rolling process was carried out at a temperature of 1080°C, and then cooled with water to freeze the microstructure. The research was conducted both for the symmetry process of peripheral working rolls and for the numerically determined optimal conditions of the asymmetrical rolling process for $a_v = 0.75$ and the deformation 18%. Numerical modeling were conducted in the range of asymmetry coefficients $a_v = 1.0$-0.75. The analysis covered both the curvature of double-layer sheets and the effect of differentiation of peripheral speed of working rolls on structural changes occurring in bimetal materials.

4. Research results and their analysis

On the basis of numerical tests, the optimal value of the asymmetry coefficient was defined, taking as a determinant the bending of the bimetal sheet. The optimal value of the peripheral speed of work rolls asymmetry coefficient for which the straight band was obtained was stated as $a_v = 0.75$. In the further part of the work, the results were presented for two representative conditions, ie asymmetry $a_v = 0.75$ (straight band and for $a_v = 1.0$ (the most bent band).

The value of the asymmetry coefficient for which the straight band was obtained was $a_v = 0.75$. In the further part of the work, in order to determine the effect of the asymmetrical rolling process on microstructural changes occurring in the bimetal materials, the results of laboratory tests for the asymmetry coefficients $a_v = 1.0$ and the deformation 18% were compared. On the basis of numerical tests, the curvature of bimetal plates was: after the traditional rolling process $1/R = 3.33$ [1/m], whereas as a for the asymmetry process ($a_v = 0.75$) it was $1/R = 0.22$ [1/m]. To compare this parameter, measurements were made after similarly rolling processes conducted in laboratory conditions and it was found that for $a_v = 1.0$ this curvature was 3.58 [1/m], while for $a_v = 0.75$ the curvature was 0.18 [1/m] (Fig. 4).

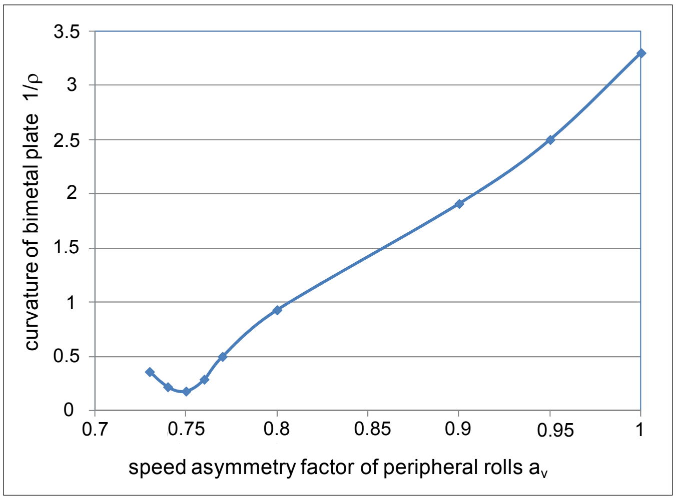

Fig. 3. The dependence of the bimetal sheet curvature on the asymmetry factor of the peripheral speed of working rolls a_v for the and deformation $\varepsilon = 0.18$

During laboratory tests, the force of metal pressure on the rollers was also measured, directly by the force and the rolling torque sensors. The measurement was made indirectly on the basis of signals received from frequency converters supplying the upper and lower roll drive motors. The average force of metal pressure on rollers during the symmetrical process was 88.8 kN, while during the asymmetrical rolling process a significant decrease of 20% was observed, to the level of 70.8 kN. The character of changes is shown in Fig. 5. The phenomenon of the drop in the value of metal pressure force on rollers is described in the literature [7] as resulting from the introduction of additional tensile stresses on the material side with higher buckling resistance and additional compressive stresses on the material side with less deformation resistance. As a result, it allows to control the unevenness of deformation of the bimetal layers as well as its curvature.

Next, based on the conducted numerical modeling and laboratory tests, a comparative analysis of the structural changes appearing during both rolling processes was made. Numeri-

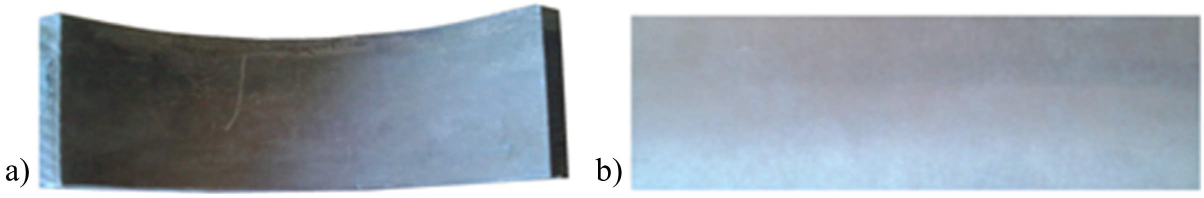

Fig. 4. View of sheets after rolling process a) symmetrical, b) asymmetrical $a_v = 0.75$

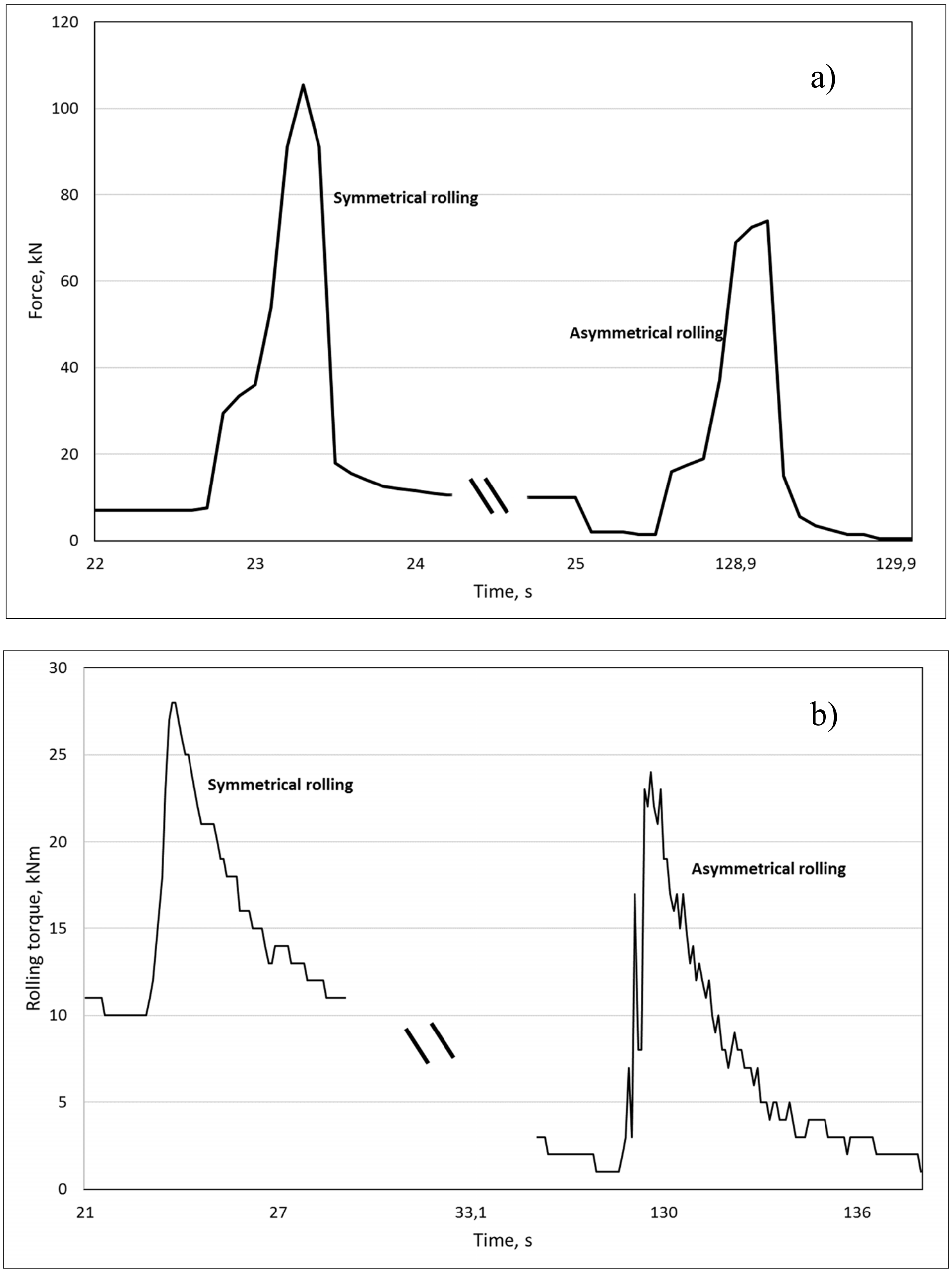

Fig. 5. The course of changes in the value of the metal pressure force on the rollers and the rotational speed of the drive motors of the upper and lower rollers, a) during symmetrical rolling, b) asymmetrical rolling

cal tests were carried out for the range of deformations from 10-25%, the physical tests however for deformation 18%. The experimental verification for the deformation of 18%, presented in the further part of the work was chosen due to the fact that grain size changes during numerical modeling were observed at this value of deformation. Figure 6 presents distributions of the average grain size for the asymmetric rolling process of bimetallic sheets X2CrNiMo17-12-2 + 10CrMo9-10 obtained during numerical calculations.

The dependence of the impact of the asymmetry of peripheral velocity of work rolls on the changes in the microstructure occurring in deformed materials, is clearly visible. On the basis of the average grain size distributions presented in Figure 6, it can be concluded that the introduction of asymmetry has a positive effect on microstructural changes. For the asymmetry of peripheral speed of working rolls (a_v = 0.75, Figure 6a), much smaller mean grain sizes were obtained. The fragmentation of the microstructure should be combined with changes in the deformation mechanism due to the asymmetry of peripheral velocity of the rolls. The occurrence of so-called shear planes described in the literature causes the appearance of new areas of privileged nucleation of new grains, which in combination with recrystallization phenomena causes a reduction in the average grain size [19].

Because the rolling process in laboratory conditions was realized at 1080°C, the determination of structural changes was possible only as a result of the so-called structure freezing. For this purpose, the samples after rolling were very quickly

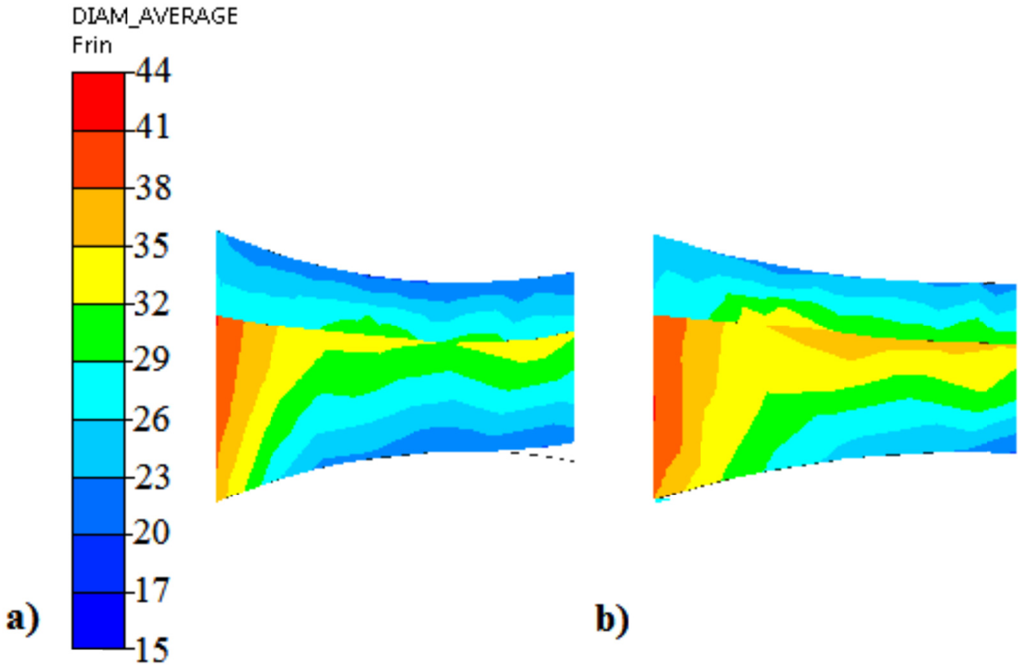

Fig. 6. Distributions of the average grain size of the asymmetrical rolling process: a) for $a_v = 0.75$ and $\varepsilon = 0.18$, b) for $a_v = 1.00$ and $\varepsilon = 0.18$

quenched with water. Next, samples were taken for microstructural investigations and a comparative analysis of the microstructure state obtained after combining with the method of explosive welding and after the symmetrical and asymmetrical rolling process was made. Microstructural investigations were carried out using the Nikon MA-200 optical microscope. To confirm the obtained test results, was made the determination microstructure changes at the height of bimetallic plates after the rolling process for $a_v = 1.0$ and $a_v = 0.75$. For this purpose, samples were made and the average grain size was determined, as shown in Figure 7. The average grain size was determined with use of the perpendicular secant method and verified by the comparison method according to the ISO 643 standard. The values obtained in both cases showed high convergence.

The distributions of the average grain size presented in Figure 7 were obtained for the same process temperature and relative deformation. The only difference was the value of the asymmetry coefficient, which indicates that the peripheral asymmetry of the speed of the work rolls had a direct impact on the grain refinement. It is connected with the introduction as a result

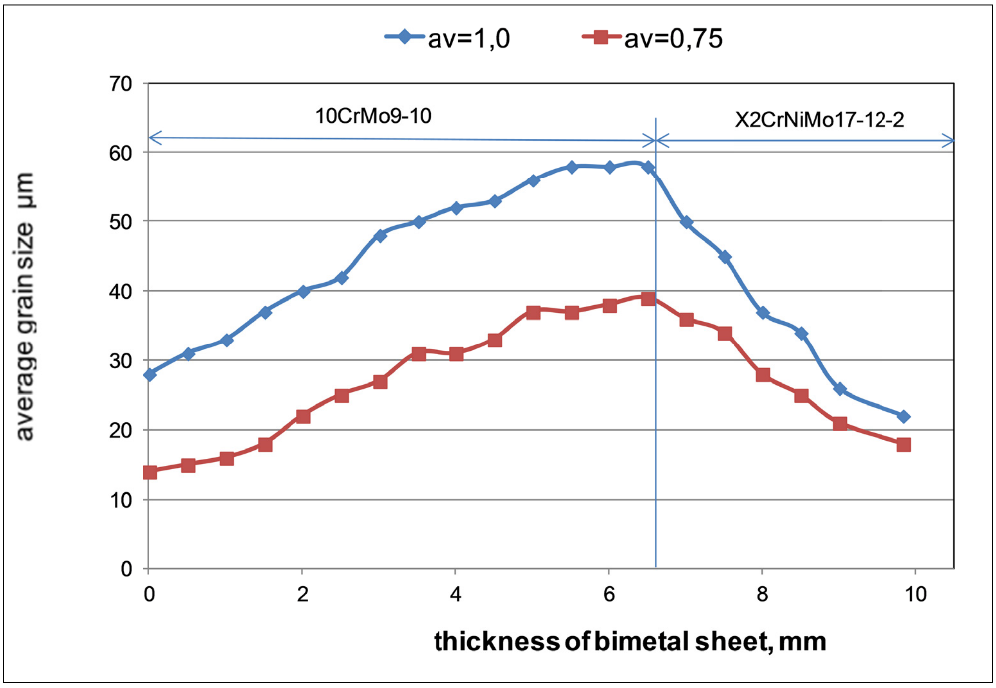

Fig. 7. The distribution of average grain size at the height of bimetallic plates after symmetrical $a_v = 1.0$ and asymmetrical rolling process $a_v = 0.75$

of asymmetry of additional stresses in the layer with a higher resistance to deformation (X2CrNiMo17-12-2) and additional compressive stresses in the layer with lower deformation resistance (10CrMo9-10).

To illustrate the discussed problem of grain refinement as a result of the applied asymmetry of the peripheral speed of working rolls, in Fig. 8 is presented the microstructure of both bimetallic sheet components in the immediate proximity of the joint area.

On figure 8 are presents microstructures of materials, constituting the bimetal, after a symmetrical and asymmetrical rolling process. A comparative grain size analysis for both bimetal components was made. After the tests, it was found that for the steel X2CrNiMo17-12-2 both before and after the symmetrical rolling the mean value of the grain size did not change and it is about 31 μm. However, in the case of the asymmetry of the speed of peripheral working rolls, its beneficial effect on microstructural changes was found because the average grain size was 22 μm. This mean reduction of 29%. This grain size reduction is obtained probably due to the greater uniformity of the total batch distribution on the bimetallic sheet layers, which directly translates into a reduction or even complete elimination of the curvature of the bimetallic band. Additionally grain size refinement will affect the increase of strength and plastic properties.

The comparative analysis of the microstructural changes in the 10CrMo9-10 steel layer was also made. In the case of rolling at uniform speeds of work rolls, the average grain size also did not change and the mean value was 44 μm. However, it was observed that a certain part of grains has grown to 70-80 μm. Such large growth was caused by a small value of deformations, which were smaller than the critical ones and led to excessive growth of austenite grains. The remaining grains size were about 25-30 μm, which indicated their fragmentation. Therefore, despite obtaining the average grain size identical to that for samples after direct joining of metals, it should be recognized that the rolling process has adversely affected structural changes in 10CrMo9-10 steel. However, after introducing the asymmetry of the rolls peripheral velocity (a_{vopt}), considerable fragmentation and increase in the uniformity of the grain size of the 10CrMo9-10 steel was observed. The average grain size is 22 μm, which means a decrease of 50%. It should also be noted that, unfortunately, not all grains have been fragmented. During the observation both large amounts of 8-10 μm grains were found indicating the occurrence of dynamic recrystallization. The analysis showed as well other grains of 50-60 μm. The appearance of the shear line, visible in Figure 6d, resulting from the introduction of asymmetry in the speed of the work rolls deserves attention. It can be assumed that the variation in speed of work rolls could have a direct impact on the grain size distribution.

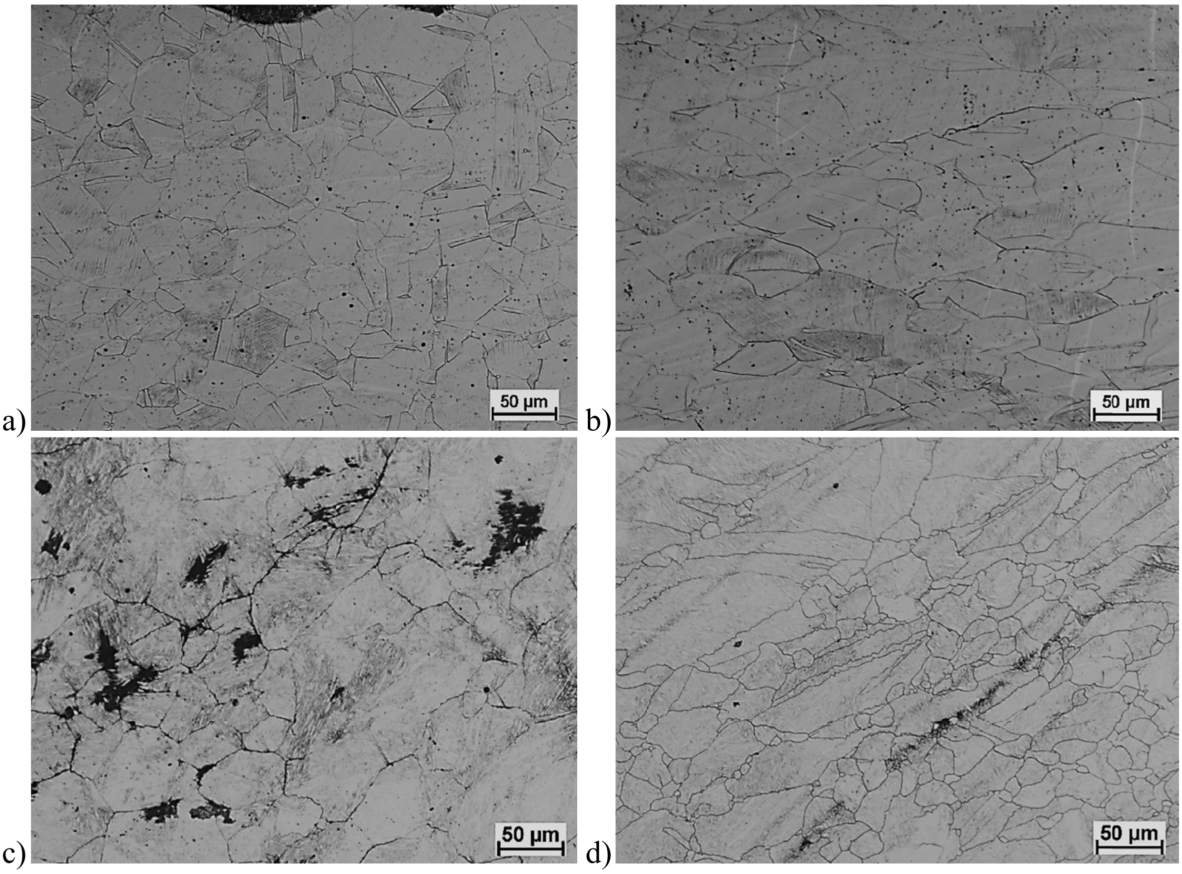

Fig. 8. Microstructure of samples after deformation 18% a) steel X2CrNiMo17-12-2 for a_v = 1.0, b) steel 10CrMo9-10 for a_v = 1.0, c) steel X2CrNiMo17-12-2 for a_v = 0.75, d) steel 10CrMo9-10 for a_v = 0.75

5. Summary and conclusions

The paper presents the results of research on the influence of asymmetric rolling process of bimetal sheets on the shape of the band after leaving the deformation gap and changes in the austenite microstructure. On the basis of the test results, it was observed that the grain refinement effect was visible for strain values of 18%. Therefore, the conducted research concerned the application of larger deformations, which resulted in greater grains refinements. The research results presented in the study allow to conclude that the introduction of differentiated peripheral velocity of work rolls, in addition to improving the quality of the band's shape, also positively affects the fragmentation of the microstructure of bimetallic sheet components. Based on the analysis, it was found that in some areas there is a strong grain refinement, while in others the size is practically unchanged.

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