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INFLUENCE OF SKIN-PASS ROLLING ON STRENGTH AND DUCTILE PROPERTIES OF EXPLOSIVE WELDED THREE-LAYERS STRIP

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ABSTRACT
Skin-pass rolling or temper rolling is the last step in cold rolling of metal sheets or strips intended for additional fabrication such as a deep drawing. The thickness reduction in the skin-pass rolling is between 0.5 to 3%. Therefore achieving high thickness reduction is not the basic reason for performing the skin-pass rolling. Basic reasons are related to: suppression of the upper yield point, elimination of the coil breaks that occurs during a strip uncoiling and improving of the strip surface quality and dimensional accuracy. The purpose of this paper is to describe the influence of the skin-pass rolling on strength and elongation of explosive welded three-layer strip consisted of CuZn10 clad layers and central DC04 steel layer.
Keywords: Skin-pass rolling, temper rolling, strength, ductility, explosive welding

1. INTRODUCTION
Deep drawing is a manufacturing process for forming flat sheets/strip into geometrical cup-shaped metal without failure or excessive localized thinning [1, 2]. In this process a sheet/strip metal blank is radially drawn into forming die by the mechanical movement of the punch to form a cup [3]. Cold rolled sheets are usually used as semi products for deep drawing. Cold rolling process increases the yield and tensile strength (work hardening) and decreases ductility so the material can become too hard to be used for any type of deep drawing. Therefore, most cold rolled sheets/strips after deformation must be annealed. The annealing process reduces strength properties and improves ductile properties so the material becomes very soft. But sheets and strips after such annealing have some unwanted characteristic so they are not suitable for deep drawing directly. For example when soft steel sheets and strips uncoil without tension a local plastic deformation (local plastic bending) will occur [4]. Also depending on chemical composition a sharp yield points (upper and lower yield stress behaviour) can occur. These phenomena reduce the surface quality of the products obtained by the deep drawing process from such sheets or strips in the form coil breaks and stretcher-strain marks on the product surfaces. These negative phenomena can be eliminated by temper or skin-pass rolling. Skin-pass rolling is the final forming step in the production of cold rolled steel sheet or strip introducing small plastic deformation [5, 6, 7, 8] to suppression of the upper yield point, elimination of the coil breaks that occurs during the sheet or strip uncoiling and improving of the strip surface quality and dimensional accuracy. The purpose of this paper is to describe the influence of the skin-pass rolling on strength and elongation of explosive welded three-layer strip consisted of CuZn10 clad layers and central DC04 steel layer.

The explosion welding process is primary used for cladding some metals with other metals having better corrosion resistance as in the case of cladding of low carbon steel with copper alloys. Explosion welding is a solid state welding process that can be used for joining metallurgically compatible metals but also metallurgically non compatible metals which are not possible to be joined by any other welding techniques. A weld surface with metallurgical bond between joined materials is produced by controlled detonation of chemical explosive [9] that is placed on cladding metal (flyer plate). Pressure created by explosive detonation directs flyer plate to the fixed base metal plate resulting in collides of them and bonding at their interface [10]. Because of high pressure produced by explosive detonation the metals at the interface are locally plastically deformed and metallurgically bonded. The pressure has to be sufficiently high and for a sufficient duration of time to achieve inter-atomic bonds [11]. Between two metal components an electron-shearing metallurgical bond is created [12] on the way that explosion forces bring metal surfaces into sufficiently close contact that valence electrons can overcome the repulsive forces resulting in sharing of their orbits [13]. Heat-affected zones are no created and there is no diffusion of the atoms of alloying element between joined metals. Also, continuous cast structure between joined metals is not created [12, 13, 14, 15, 16].

2. EXPERIMENTAL PROCEDURE AND RESULTS

Samples for rolling were three-layers plate obtained by explosive welding. The plates of copper alloy (CuZn10 according to the standard EN 1652) were welded to the plate of low carbon steel (DC04 steel for deep drawing according to the standard EN 10130) on both sides (top and the bottom side) of the steel plate. Chemical composition of the particular layers is presented in Table1.

Table 1. Chemical composition of the steel DC04 layer and clad CuZn10 layers

Material	Composition in mass %									
	C	Mn	Si	P	S	Al	Cu	Zn	Pb	Fe
DC04	0,08	0,30	0,03	0,009	0,003	0,023	-	-	-	Rem.
CuZn10	-	-	-	-	-	-	89,9	10,1	<0,01	<0,01

The dimensions of the three-layers plate obtained by explosive welding were 1200x2000mm. Samples (strips) of nominal width 90mm were cut by water jet from the three-layers plate. The rolling was performed on Light section rolling mill SKET ϕ370mm from 34,8mm to 4,3mm of thickness (8 passes), and Laboratory light section rolling mill ϕ250mm from 4,3mm to 2,3mm of thickness (3 passes). The relative total height reduction for the first eight passes is 87,7%, the relative total height reduction for the last three passes is 46,5%. Cumulative total height reduction for all eleven passes is 93,4%. After hot rolling and recrystallization annealing (700^{o}C/1h) but before cold rolling an oxide film from strip surface has been removed by 7,5% sulphuric acid heated on temperature 35-40^{o}C. Holding time of the strip in sulphuric acid was 8 minute. Cold rolling of the three-layer strip was performed on the cold rolling mill LOMA from 2,33mm on 1,33mm of thickness. After final recrystallization annealing (700^{o}C/1h) a newly formed oxide film has been removed on the same way as after hot rolling. The microstructure (Figure 1.) consisting of ferrite with complete spheroidized cementite is a common microstructure obtained after performing the described thermomechanical treatments [17]. Thickness of the individual layers are 0,098 and 0,094 mm in the case of clad CuZn10 layers and 1,138 mm in the case of central steel layer [18]. Skin-pass rolling was performed from thickness 1,33mm on thicknesses 1,32; 1,31; 1,30; 1,29; 1,28 and 1,27 mm. Tensile tasting of the obtained strips was performed according to standard BAS EN ISO 6892-1:2017. Results of tensile testing are presented on Figure 2. and in Table 2.

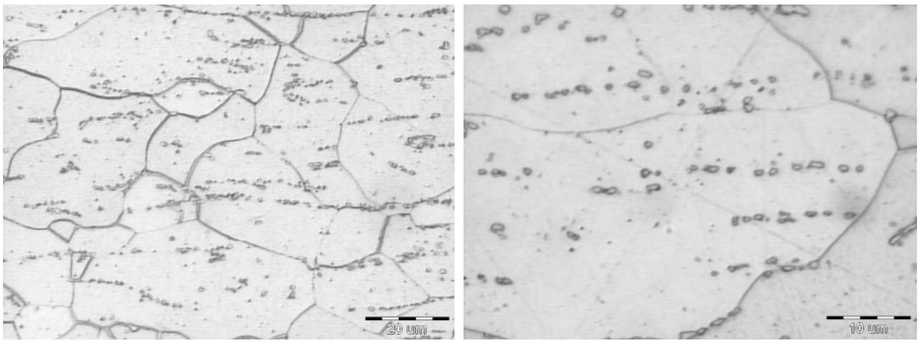

Figure 1. Microstructure of the three-layers strip after hot and cold rolling and recrystallization annealing

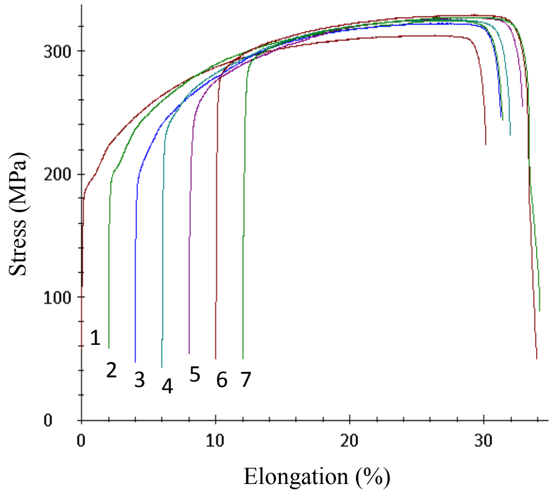

Figure 2. Tensile test diagrams of the samples with different amount of cold deformation

Table 2. Tensile test results of the samples with different amount of cold deformation

Ordinal number	Height reduction of the strip (%)	Yield strength Rp0,2 (MPa)	Tensile strength Rm (MPa)	Elong-ation (%)
1.	0,00	188	313	29,5
2.	0,75	199	325	28,5
3.	1,50	198	322	27,5
4.	2,26	233	325	25,5
5.	3,01	239	327	24,5
6	3,76	275	329	23,0
7.	4,51	277	327	23,0

3. DISCUSSION

The sum of the thickness of the upper and lower coated layers is 0,192mm in the three-layers strip with total thickness of 1,33mm so the ratio of thickness of the clad layers and total strip thickness is 14,4%. Alloy CuZn10 has no pronounced upper and lower yield stress unlike some types of annealed steel. Although the thickness of clad CuZn10 layers in the total thickness of the three-stranded strips is small (14.4%), the three-layer strip does not exhibit upper and lower yield points in annealed state (Table 2., ordinal number 1.) and also in other states after skin-pas rolling. Due to in a three-layer strips of this type the skin-pass rolling is not used for suppression of the upper yield point but it is used for elimination of the local plastic bending of the strip and coil breaks that occurs during the strip uncoiling and improving of the strip surface quality and dimensional accuracy (Figure 3.). With height reduction of the three-layer strip during skin-pas rolling yield strength increases while elongation decreases. On the other hand, the tensile strength did not change significantly (Figure 4.).

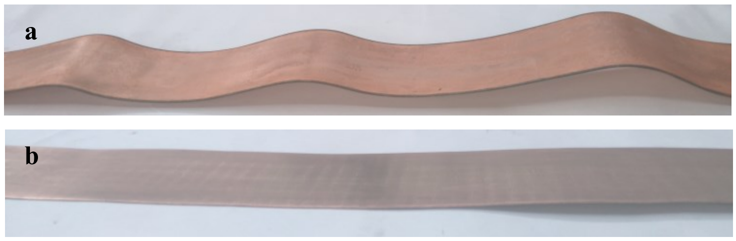

Figure 3. Different behaviour of the three-layers strip during uncoiling before (a) and after skin-pas rolling (b)

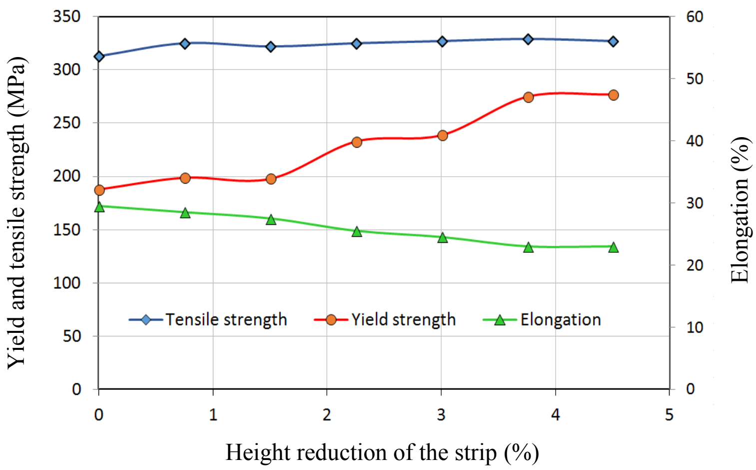

Figure 4. Change of strength and elongation with the increase of the amount of cold plastic deformation during skin-pass rolling

4. CONCLUSIONS

Skin-pass rolling eliminates the local plastic deformation (local plastic bending) of the three-layers strip during its uncoiling and thus the emergence coil breaks on the strip surfaces. Also, skin-pass rolling improves the strip surface quality and dimensional accuracy. The three-layers strip does not exhibit upper and lower yield points in annealed state and also in other states after skin-pas rolling. Tensile strength of the three-layers strip is not changed significantly with increasing the amount of cold deformation within skin-pass rolling. On the other hand, yield strength increases while elongation decreases with increasing the amount of cold deformation within skin-pass rolling (more significant for amount of cold deformation above 2%).

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