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THE EFFECT OF ANNEALING ON MECHANICAL PROPERTIES OF AUTOMOTIVE STEEL SHEETS

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This paper deals with mechanical properties of galvannealed automotive steel sheet. The composition of the zinc coating modifies as a result of the annealing after galvanizing, thereby its local mechanical properties change. Presented research is therefore aimed at determination the change in tensile properties of steel due to annealing, which is an important part of galvannealing technology. Annealing of galvanized steel samples was carried out at 500 °C with different holding times at annealing temperature. Changes in both tensile strength and normal anisotropy coefficient, a decrease of yield strength and an increase of ductility were found for examined steel.

Keywords: IF steel, sheet, galvanneal, annealing, mechanical properties.

INTRODUCTION

Steel is a traditional material used in the production of sheets [1] for the automotive industry which is currently the most dynamically developing industry. Its rapid development is largely facilitated by continuous improvement of functional properties and quality of automobiles. This work is focused on the tension properties of galvanised steel intended to be used in automobiles – a deep-drawing IF (Interstitial Free) steel. The effect of annealing on the tensile properties of galvanised IF steel was determined.

One of the metal coatings used to protect steel, is the zinc coating [2]. Zinc coatings belong to the best known and the longest applied methods of protection of metal products against corrosion. The reason why zinc is used is its ability of excellent anticorrosive protection with regard to the double effect of the coating: (i) the barrier effect and (ii) the cathodic protection. Galvanising steel by dipping it into molten zinc is the most important and most frequently used method of surface protection [3]. This technology is used in continuous processes, such as hot-dip galvanising of straps and wires, in semiautomatic lines for hot-dip galvanising of pipes, as well as hot-dip galvanising of various types of steel parts and structures in the process of piece galvanising. The automotive industry is a significant consumer of galvanised steel sheets. At present, a major part of galvanised steel sheets is manufactured by hot-dip galvanising in continuous lines using the technology referred to as the Sendzimir process.

Hot-dip galvanising is a metallurgical process in which a coating is formed on the steel surface as a result of the reaction between the base material and molten zinc in a bath. The result thereof is a multi-phase composition of the zinc coating [4]. The reaction between pure-metal steel surface and molten zinc produces, in an order corresponding to the phase equilibrium diagram of Fe – Zn [5]. In a continuous process, it is possible to suppress the formation of several layers by adding Al into the bath in the amount of 0,15 – 0,30 % [6]; this brings overall improvement in the adhesion of the Zn coating due to the formation of a Fe_2Al_5 semi-layer [4] which prevents the reaction between Fe and Al. The addition of 0,2 to 0,3 % Al results in the formation of the layer of pure Zn. Only after the Fe_2Al_5 interim layer is dissolved, normal formation of intermetallic phases begins, even faster than without aluminium [5].

Galvanneal coatings [4] are formed by galvannealing which may be preceded by hot-dip galvanising, electrolytic galvanising, or vapour galvanising, most frequently within the temperature range of 440 – 550 °C. The galvannealing after galvanising is the process that results in the transformation of pure Zn inside the coating into intermetallic phases Fe – Zn through diffusion between Zn and the steel base.

EXPERIMENTAL
Steel

For experiments was used deep-drawing IF steel with ferrite microstructure, chemical composition is presented in Table 1. Mechanical properties (0,2 % offset yield strength $R_{p0,2}$, tensile strength R_m, elongation A_{80}, normal anisotropy coefficient r and strain hardening exponent n) are shown in Table 2.

IF steels are used for production extra deep drawing hot-dip galvanized sheets for demanding automotive stampings [7]. With respect to the desired properties of conditional development of adequate texture and more

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Table 1 **Chemical composition of IF steel**

Chemical composition / wt. %				
C 0,005	Mn 0,298	Al 0,0439	P 0,059	S 0,008
Si 0,008	Ti 0,034	Nb 0,039	Cu 0,021	Cr 0,012
Ni 0,009	As 0,006	N 0,003	V 0,001	Zr 0,001
Sn 0,003	Sb 0,002	Mo 0,002	B 0,001	

Table 2 **Mechanical properties of IF steel**

Steel	$R_{p0,2}$ / MPa	R_m / MPa	A_{80} / %	r	n
IF	281	386	32,8	1,95	0,19

stringent requirements concerning, for example aging, it is necessary to attach the greatest extent possible and as low concentrations of dissolved interstitial compounds to stable carbide formers and nitride formers [8]. IF steels have interstitial C and N atoms untied to stable forms, and that don't require additional overage and may be processed at a high heating rate and movement of the band and which are necessary for galvanizing or continuously annealing [9]. IF steels were developed to achieve extremely high deep drawing levels. This property is preferred at the expense of strength values, which normally degrades the ability of deep drawing [10–12].

In terms of physical metallurgy, the nature of IF steels is simple. It is a structure of very pure ferrite, which properties are controlled mainly by grain size. Difficulties arise in choosing practical measures that lead to their optimum size, conditional upon the desired anisotropy of properties. Microalloying elements Ti, Nb, or their combinations play an important role not only in binding free interstitials improving ductility and resistance to deformation aging, but also in the kinetics of recrystallization. It should be pointed out, that the appropriate choice of their contents is not unambiguous and is always dependent on the possible thermal conditions of hot rolling, or on annealing parameters of cold rolled strips [7].

Thermodynamic conditions of hot rolling of IF steels, in particular the entrance heating temperature of slabs, the rolling temperature, the strip cooling rate from the rolling temperatures should be chosen with regard to the knowledge of the recrystallization kinetics and particle precipitation processes. The precipitate is already present after hot rolling in all types of IF steels. The dispersion of precipitates and the carbon state play a very important role in recrystallization inhibiting [8].

Achieving the potential of the deep-drawing properties offered by IF steels is possible directly by galvanizing on continuous lines, providing controlled hot rolling that allows controlled precipitation of TiCN in both size and particle number. The hot rolling is carried out at temperatures above 900 °C in the austenitic region where the TiCN particles are completely dissolved.

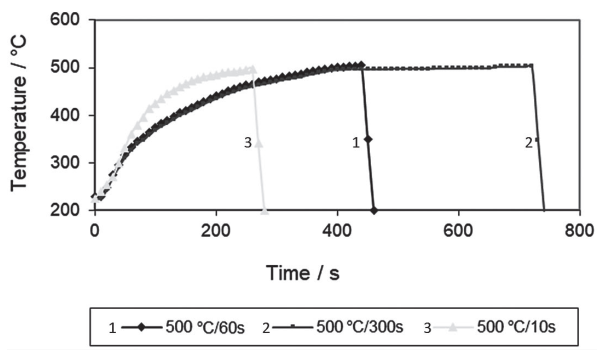

Figure 1 Annealing of IF steel

Their precipitation is effected by subsequent cooling and curling. Curling temperatures should be relatively high, but with respect to belt moridity, they are maintained at 650 to 690 °C. The cold rolling is done by removing 70 to 80 %, after which the texture of type (111) has been favorably developed [10].

IF steels have a very low yield point, below 160 MPa, and are fully ageless due to the absence of interstitial reinforcement. The steels have a high ductility above 42 %, a mean normal anisotropy coefficient *r* above 1,7 and also a high strain hardening exponent *n* [10].

Annealing

Samples were annealed at 500 °C in a furnace type 7/5 KPO with forced circulation by contact heating on the refractory brick, followed by cooling in air, for 3 different times: 10, 60, and 300 s (Figure 1). Longer annealing times were chosen because of the higher phosphorus content in the steel, which affects the composition of the galvanneal coating [12].

RESULTS AND DISCUSSION

The Figure 2 describes the uniaxial tensile testing the IF steel in all states, aimed to identify the strain characteristics corresponding to the given stresses. There are obviously different mechanical properties. Obtained values after annealing are listed in Table 3.

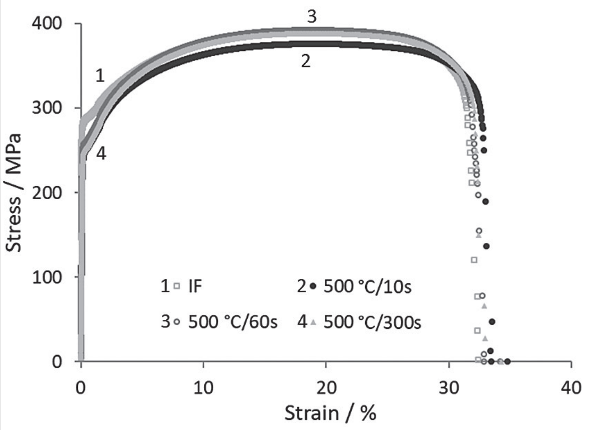

Figure 2 Stress-strain diagram of examined steel, IF - designation for unannealed state

Table 3 **Mechanical properties of annealed steel**

Annealing	$R_{p0,2}$ / MPa	R_m / MPa	A_{80} / %	r	n
500 °C/10 s	249	376	33,5	2,1	0,19
500 °C/60 s	257	392	33	2	0,19
500 °C/ 300 s	251	387	33,2	1,9	0,19

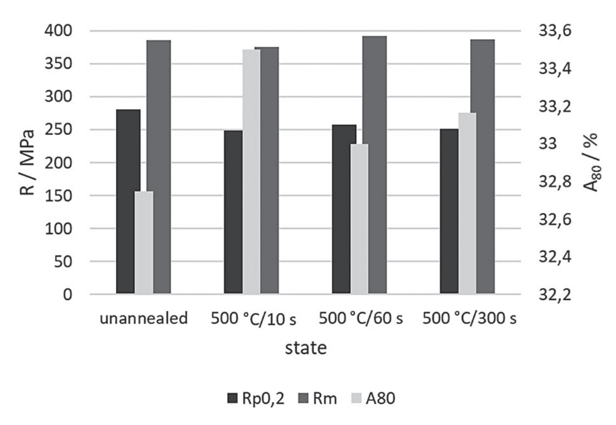

Figure 3 Histogram of obtained mechanical properties - yield strength $R_{p0,2}$, tensile strength R_m, elongation A_{80}

The mechanical properties of the examined steel after annealing differ. Measured yield strength $R_{p0,2}$, tensile strength R_m, elongation A_{80} and normal anisotropy coefficient *r* are different. Strain hardening exponent *n* hasn't changed after any annealing.

Yield strength of annealed samples of IF steel is lower by 8,5 – 11,4 % than in the initial state. Tensile strength after annealing lasting 10 s is decreased by 2,6 %, it increased by 0,3 – 1,6 % for the other annealing (both 500 °C/60 s and 500 °C/300 s). The maximum value was find on annealing 500 °C/60 s. Elongation of the annealed samples of the investigated steel is higher by 0,6 – 2,1 % than for unannealed steel. The maximum elongation occurred at annealing 500 °C/10 s. Normal anisotropy coefficient of annealed states differ from default state in the range -2,6 – 7,7 %. Figure 3 documents the comparison of determined mechanical properties.

CONCLUSION

The galvannealing technology [13], consisting in annealing of galvanised steel sheets, was applied to the specimens of deep-drawing hot-dip galvanised IF steel sheet. Galvannealing modified the composition of the zinc coating which after the annealing consisted of intermetallic phases Zn – Fe. As a result, its mechanical properties change. The results of the experiments confirmed the change of both tensile strength and normal anisotropy coefficient, a decrease of yield strength and an increase of ductility of annealed samples of IF steel.

Acknowledgements

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Note: The English Language translation was done by Miriam Valčáková, Košice, Slovakia.