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AUTO BODY SHEETS FOR A NEW CAR GENERATION

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This paper deals with the development of hot - and cold - rolled sheets designed for automotive industry. The achieved properties of some grade sheets after simulation of technological processes in the laboratory conditions are compared to the common properties of individual sheet groups. The attention is paid to the processes of hot rolling with the accent to the ferittic rolling.

Key words: *auto body sheets, hot and cold rolled sheets*

Limovi za karoserije auta nove generacije. Rad se bavi razvojem toplo i hladno valjanih limova, namijenjenih industriji auta. Dobivena svojstva nekih kvalitetnih čelika nakon simulacije tehničkih procesa u laboratorijskim uvjetima uspoređuju se s zajedničkim svojstvima pojedinih grupa limova. Govori se također o procesima toplog valjanja s naglaskom na feritno valjanje.

Ključne riječi: *limovi za karoserije auta, toplo i hladno valjani limovi*

INTRODUCTION

Technical development of modern car concept at present is directed towards the decrease of its weight, from which saving of fuel is possible with the consequential decrease of gas pollutant emission. The total weight of middle class car is as follows [1]: body - 26 %, chassis - 23 %, engine - 21 %, liquid media - 5 %, and electricity - 3 %. The development aims are concentrated to provide more comfort i.e. to extend the car furnishing and therefore best opportunities to reduce the total car weight will be in decrease of body, under cart and engine weight. According to the Chrysler plans the future relative weight decrease should be: body by 50 %, chassis by 50 %, engine by 10 % and fuel system by 55 %. Those changes should reduce middle class car weight from ca 1450 kg at present to ca 870 kg, i.e. weight decrease by approx. 40 %. An average European car of middle class has lower weight of approx. 1100 kg. Its total weight is the sum of: steel and alloys - 62%, non-ferrous metals (Al, Mg) – 8 %, plastics - 10 %, rubber - 4.5 %, glass - 3 %, textile and anti-noise materials - 4 %, paint and binder - 1.5 % and liquids and other materials - 7 % [2]. The material expenses represent about 30 % of total car price. In the light of perspective of American car development, the future car should be able to travel 80 miles consuming just 1 gallon of fuel, i.e. fuel consumption 2.6 l per 100 km.

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In this paper, attention will be paid to the materials of body and, marginally also, to the materials for dynamically strained auto parts like under cart and wheels. The development of structural hot rolling sheets and cold rolling sheets for automotive industry is documented in Figure 1. [3]. It follows from the figure, that the application of new production technologies by the metallurgical producers is concentrated to the increase of service properties of newly developing steel grades and this trend is clear starting from the year of about 1980. The classical micro-alloyed steels of ZStE grade were replenished with rephosphoring steel grade

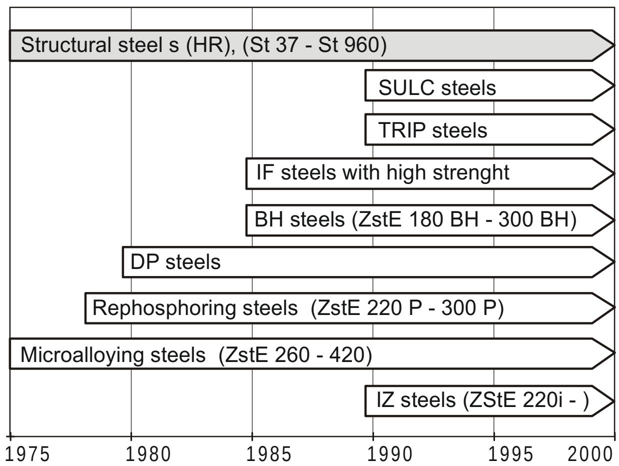

Figure 1. **Development of hot and cold rolled sheets for autobody parts**
Slika 1. **Razvoj toplo i hladno valjanih limova za dijelove karoserije auta**

ZStE P and two phase DP steels. During middle of eighties the IF (interstitial free) steels with higher strength and BH (bake hardening) steels have been developed.

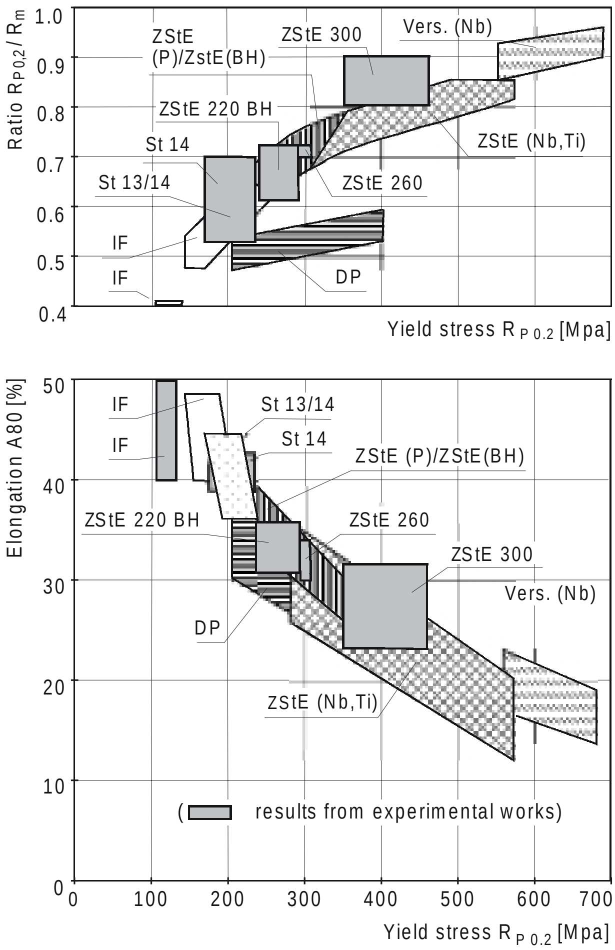

Figure 2. **Properties autobody sheets after cold rolling**
Slika 2. **Svojstva limova za karoseriju nakon hladnog valjanja**

The development of properties of basic classes of cold - rolled steel sheets or strips designed for auto body parts of car is shown in Figure 2. [4], Figure 3. [5] and Figure 4. [6].

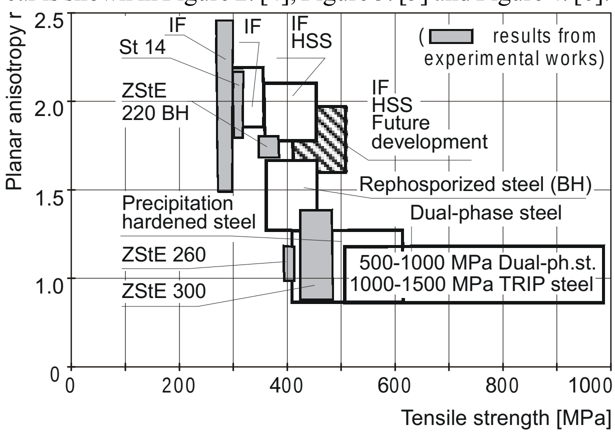

Figure 3. **Dependence of planar anizotropy on tensile strenght**
Slika 3. **Ovisnost planarne anizotropije o vlačnoj čvrstoći**

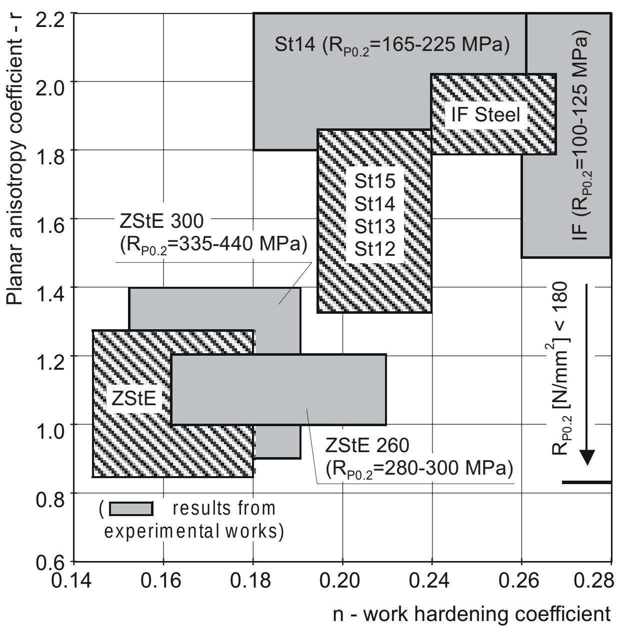

Figure 4. **Drawability of some steel sheet grade**
Slika 4. **Sposobnost izvlačenja nekih kvalitetnih čeličnih limova**

The increase of strength as well as good plastic properties (drawability) of cold rolled sheets can be achieved, from the physico-metallurgical point of view, only via guarantee

Table 1a. **Hot rolled high strength steels for autobody parts**
Tablica 1a. **Toplo valjani visokočvrsti čelici za dijelove autokaroserije**

Strengthening mechanism		Main alloying elements	R_m [MPa]	Characterization	Practical application
solid solution (SS)		Si-Mn No Nb+V	490 - 590	good bendability	structural components of frame, chassis par.
precipitation (P)		Nb, Ti, V Nb+Ti Nb+Ti+Cr	490 - 780	drawing type, high strength flangeability	structural components, vheel rims brackets
	M + F	Si-Mn Si (Cr, P, Mo)	540 - 980	high elongation low yield stren. low $R_{p0.2}/R_m$ rat.	structural components, vheel rims brackets
transformation	B + F	Si-Mn Si-Mn-Nb Cr, Ti+Cr	440 - 780	high elongation	hinges, engine holder
(T)	M + B	Si, Ti	590 - 780	high hole expanding ratio	chassis parts,impact exposed reinforc.of doors
	retain.A	C, Si Si-Mn (Cr, P)	590 - 980	TRIP type, h.el. good balance between strength and ductili.	bampers, chass. parts, vheel dis. impact exposed reinforc.of doo.

of suitable metallurgical conditions for application of various mechanisms of strengthening. The following mechanisms can be applied during the production of auto body sheets:
- solid solution strengthening;
- dislocation strengthening;

- strengthening of grain boundaries;
- precipitation strengthening;
- transformation strengthening.

Table 1b. **Cold rolled high strength steels for autobody parts**
Tablica 1b. **Hladno valjani visokočvrsti čelici za dijelove autokaroserije**

<table>
<tr><th colspan="2">Strengthening mechanism</th><th>Main alloying elements</th><th>R_m [MPa]</th><th>Characterization</th><th>Practical application</th></tr>
<tr><td colspan="2">solid solution (SS) (LC-low carbon)</td><td>P-Mn
Si-Mn
P</td><td>340 - 440</td><td>drawing type
good stretchability
BH type</td><td>external panels, internal panels, structural elem. brackets, pillars</td></tr>
<tr><td colspan="2">solid solution (SS) (ULC-ult. low carb.)</td><td>P-Mn
P-Si
Mn-P-Si
Ti, Nb</td><td>340 - 590</td><td>deep-drawing type
BH type</td><td>deep-drawing parts,
external panels, internal panels</td></tr>
<tr><td colspan="2">precipitation (P)</td><td>Mn
Nb
Si-Mn-Nb</td><td>390 - 590</td><td>good weldability</td><td>internal panels</td></tr>
<tr><td colspan="2">solid sol.+ precipitat. (SS+P)</td><td>Mn-Ti
Si-Mn-P-Nb,Cu-Ti</td><td>490 - 590</td><td>good bendability, high “r” value type</td><td>reinforcements, brackets</td></tr>
<tr><td rowspan="3">transformation (T)</td><td>M B + M</td><td>Mn-Si,
Mn-Si-P
Mn
Si-Mn-Nb</td><td>490 - 1470</td><td>low $R_{p0.2}/R_m$ ratio,
BH type</td><td>internal panels, structural elem. reinforcements, bampers</td></tr>
<tr><td>B</td><td>Mn-Cr</td><td>440 - 590</td><td>high stretch flangeability, high elongation</td><td>structural elem. reinforcements, brackets</td></tr>
<tr><td>retain. A</td><td>Si-Mn</td><td>590 - 980</td><td>TRIP type, high elongation</td><td>structural elements</td></tr>
<tr><td colspan="2">precipit.+ transformation (P+T)</td><td>Mn-Si-Ti
Mn-Si-Ti-Mo</td><td>780 - 1470</td><td>ultra-high strength</td><td>bampers, reinforcements, impact reinforcemen.of doors</td></tr>
</table>

Application of strengthening mechanisms during production of hot - and cold - rolled high strength steel sheets which show better plastic properties is given in Table 1a [7] and Table 1b [7].

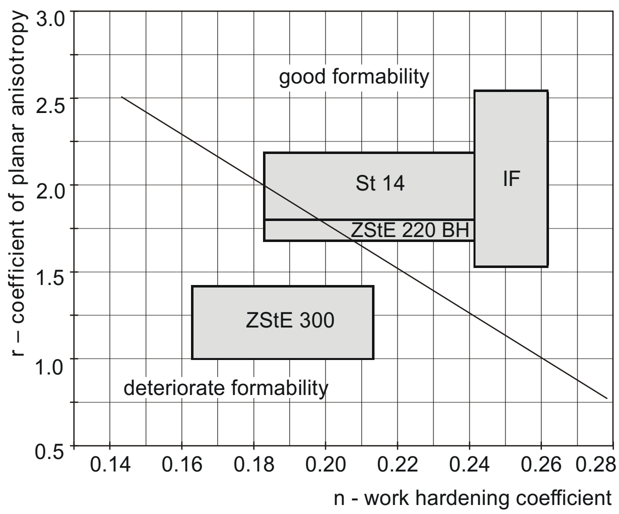

Figure 5. **Formability some steel sheets for autobody parts**
Slika 5. **Obradivost nekih čeličnih limova za dijelove karoserije auta**

EXPERIMENTAL STUDY OF AUTOMOTIVE SHEETS GRADES

The effects of hot and cold plastic deformation, cooling rate, and conditions of annealing were experimentally studied on the research level in order to determine techno-

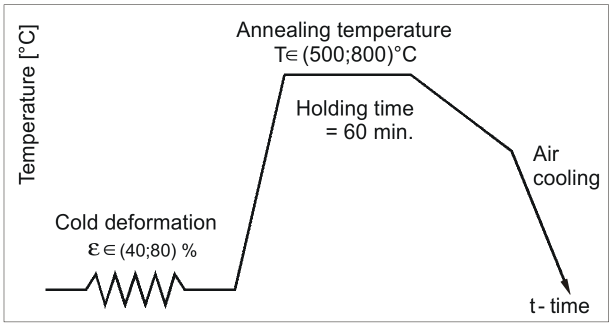

Figure 6. **Experimental schedule of IF steel**
Slika 6. **Program ispitivanja za IF čelik**

Table 2. **Experimentally tested materials and their properties after laboratory simulations**
Tablica 2. **Ispitivani materijali i njihova svojstva poslije laboratorijske simulacije**

No	Material grade	Main elements	Mechanical hardening	Composition							
				C [%]	Mn [%]	Si [%]	P [%]	S [%]	Nb [%]	Ti [%]	V [%]	Al [%]
1.	St14	Mn	TR	0.06	0.23	-	0.008	0.014	-	-	-	0.040
2.	ZStE220BH	Mn+Si+P	TR+DS+P	0.04	0.20	0.27	0.054	0.012	-	-	-	0.051
3.	ZStE260	Mn+Nb	TR+P	0.07	0.42	0.20	0.016	0.007	0.020	-	-	0.060
4.	ZStE300	Mn+Nb+Ti	TR+P	0.07	0.92	0.02	0.012	0.010	0.036	0.040	-	0.056
5.	IF	Mn+Ti	TR	0.002	0.12	0.007	0.008	0.004	-	0.095	-	-
6.	QStE380TM	Mn+Nb+Ti	TR+HZ+P	0.10	0.90	0.01	0.011	0.008	0.031	0.041	-	0.041
7.	QStE460MC	Mn+Nb+Ti	T+P(B+F)	0.09	1.12	0.02	0.010	0.009	0.040	0.070	0.003	0.005
8.	ZINKODUR 260	Mn+Si+Nb+Zr	TR+P	0.08	0.39	0.17	0.014	0.014	0.033	Zr0.033	-	0.090
9.	ZINKODUR 300	Mn+Si+Nb	TR+P	0.07	0.72	0.21	0.070	0.008	0.027	Zr0.027	-	0.030

logical conditions of materials treatment designed for automotive industry. Experimental studies were directed mostly to the steel materials given in Table 2.. The achieved results of the laboratory simulations for hot rolling sheets are shown in Figure 2., Figure 3., Figure 4., Figure 5..

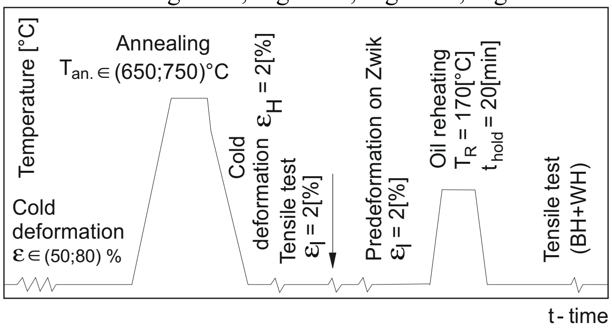

Figure 7. **Experimental schedule of BH steel**
Slika 7. **Program ispitivanja za BH čelik**

The plan of experiments for monitoring of IF steel properties is given in Figure 6. and that for ZStE 220 BH steel in Figure 7.. The results of static strain tests as well as their combinations $P = R_m/R_{P0.2}$; KUT = P.A80; IT = $1000.r_s.n_s$ were used for the evaluation of properties. The main aim of experimental research is in evaluation of rolling conditions and annealing in order to achieve optimal properties of the tested materials.

ANALYSIS OF THE ACHIEVED RESULTS

a) IF steel

IF steels should not contain any freely soluble atoms of the interstitial elements (C, N_2) and therefore the elements with high affinity to them such as Ti, Nb, Ti+Nb, B are used for their binding. IF steels are employed for the production of the most demanding high precision big part of auto body the pressing pieces and must possess the following properties:

- high deep-drawing on the EDDQ or SEDDQ class with coefficient of normal anisotropy r = 1.9 - 2.5;
- low yield strenght of 100-160 MPa, coefficient of work hardening n ~ 0.25 and ductility up to 55%;
- corrosion resistance, which is achieved by zinc coating.

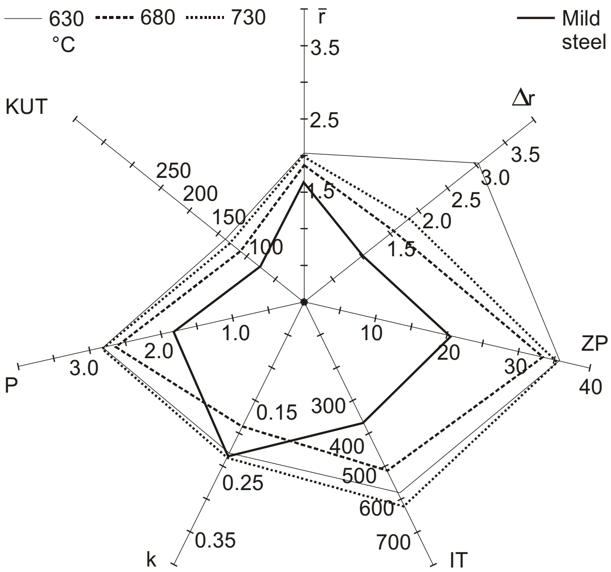

Figure 9. **Diagram of formability coefficients as function of annealing**
Slika 9. **Dijagram koeficijenta obradivosti kao funkcija žarenja**

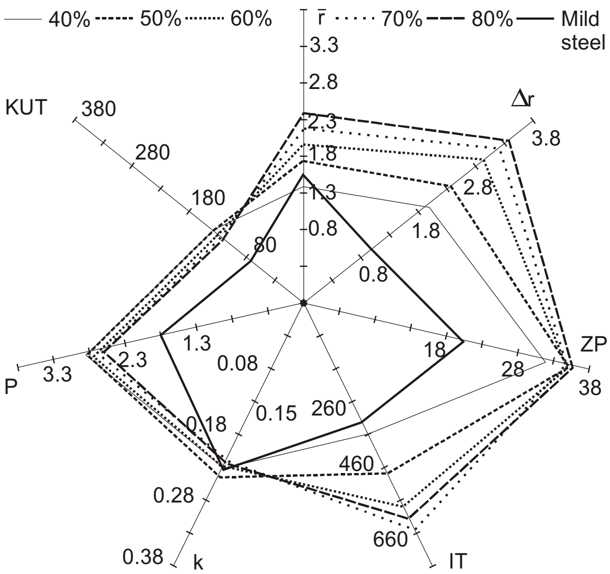

Figure 8. **Diagram of formability coefficients as function of deformations**
Slika 8. **Dijagram koeficijenta obradivosti kao funkcije deformacia**

The achieved results expressed as the forging criteria are given in the radar diagrams - Figure 8. and Figure 9.. It follows from the graphical relationships that:

- P, KUT and k parameters are sensitive mainly to the annealing temperature while deformation has minor influence;
- IT parameter is sensitive mainly to the deformation magnitude with minor influence of annealing temperature;
- almost all experimental results lie within the area of good formability and increasing degree of deformation shifts them to the better values;
- selected modes of treatment allow to achieve safely the material drawability on the EDDQ class with annealing temperature T_{anneal}=680 °C and cold deformation degree at the level of ε = 50 - 60 %.

b) ZDtE 220 BH steel

BH effect is employed mainly for the sheets designed for big part of the pressing pieces of auto body parts (car roof, car hood, doors) for which the impression stability is required after pressing and painting works. Main advantage of BH sheets lays in their low yield strenght and high formability parameters before pressing while after pressing and painting works the deformation-thermic strengthening takes place and consequently the yield strenght is increased to by 30 - 90 MPa. The strengthening process is related to the hot mechanical ageing which is determined by the segregation of the carbon and nitrogen atoms to the

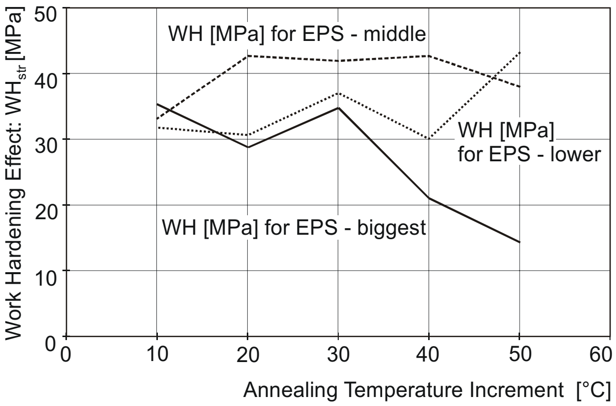

Figure 10. **Work hardening effect as function of annealiing temperature increment**
Slika 10. **Efekt očvršćivanja obradom kao funkcija povećanja temperature peći**

dislocations generated during pressing. The ageing process is controlled through thermic activation of carbon atoms, which are dissolved in the deformed ferrite and subsequently, during paint bake due to the diffusion movement concentrates around dislocations and forms Cottrel atmosphere. Parameter P is regarded as the important element to achieve BH effect, which segregates in the ferritic

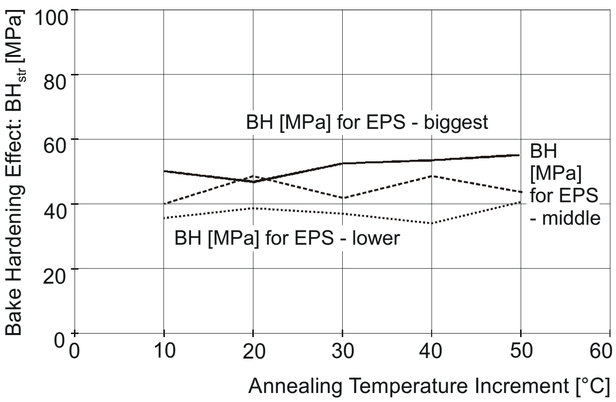

Figure 11. **Bake hardening effect as function of annealiing temperature increment**
Slika 11. **Efekt očvršćivanja u peći kao funkcija povećanja temperature žarenja**

zone boundaries during annealing and thus obstructs the formation of cementite nucleus what results in preferred utilization of carbon atoms for diffusion movement to the dislocation vicinity.

The achieved results of experimental tests are given in Figure 10., Figure 11., Figure 12. from which follows:

- most stable values of WH (work hardening) effect are achieved for the deformation higher than 60 % and annealing temperature above 680 °C;
- highest values of BH effect - on the level of BH = 54 MPa - has been achieved for the deformations higher than 70 % and annealing temperature above 690 °C;
- maximal effect (BH + WH), as the characteristic which determines drawability of material, has been achieved for $\varepsilon = 65$ % and $T_{anneal} \geq 700$ °C.

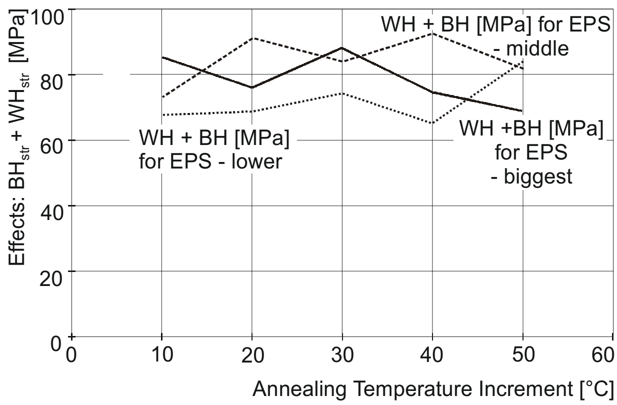

Figure 12. **BH + WH effect as function of annealiing temperature increment**
Slika 12. **Efekti BH +WH kao funkcije povećanja temperature peći**

NEW ROLLING TECHNOLOGIES

The steels for car sheets can be categorized according to the carbon content as follows:

- LC steels (low carbon): 0.03 - 0.25 %C;
- ELC steels (extra low carbon): 0.005 - 0.02 %C;
- ULC steels (ultra low carbon): 0.002 - 0.005 %C;
- SULC steels (super ultra low carbon): < 0.002 %C.

From the general point of view, the technological processes applied for hot rolling strips designed for automotive industry are as follows:

- conventional rolling;
- controlled rolling and controlled cooling for:
    - high strength, rephosphorized and two phase steels;
    - ELC, ULC and SULC steels with the possibility to apply ferritic rolling.

Ferritic hot rolling for ULC and ELC steels brings considerable improvement of the starting conditions for the subsequent cold rolling and annealing. The research in this field has began at the end of eighties and in the beginning of nineties. The comparison of various hot rolling processes is summarized in Figure 13.. The ULC and ELC steels type are, in comparison with LC steels type, suitable for ferritic rolling because due to the lower carbon

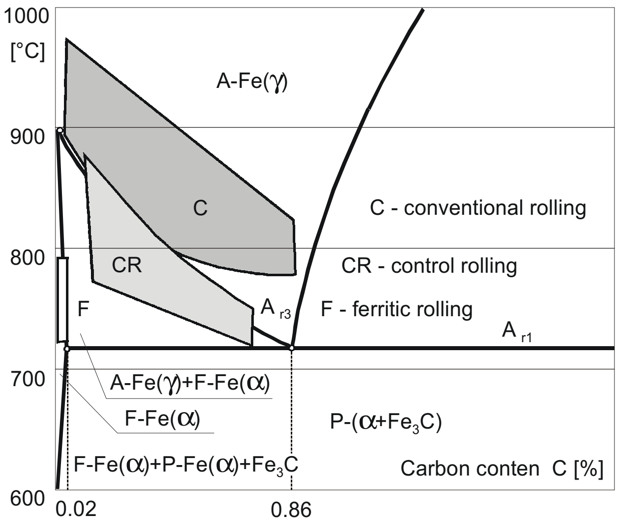

Figure 13. **Comparison of some hot strip rolling proceesses**
Slika 13. **Uspoređivanje nekih procesa valjanja toplih traka**

content the beginning of austenite phase transformation starts already at 900 °C, what is documented in Figure 14 [8 - 11]. ULC and SULC steels are most suitable for ferritic rolling because due to ultra low carbon content the direct austenite phase transformation to ferrite begins at 910 °C. The fundamental gains from ferritic rolling can be, according to the Bleck et. al and Essien et al, described as follows:

- decrease of the production costs of hot rolling (low heating temperature, decreasing steel oxidation during heating, decreasing of water comsumption during controlled cooling);

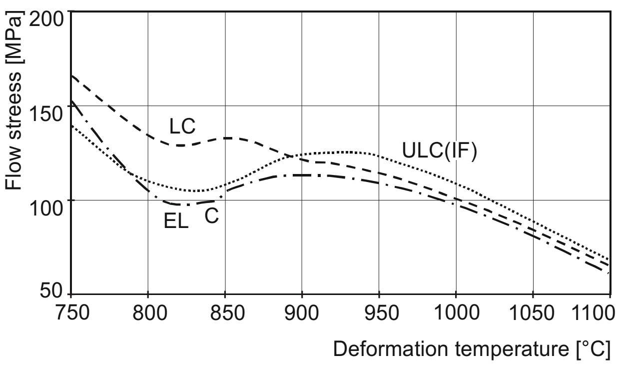

Figure 14. **Dependence of flow stress on deformation temperature for LC, ELC, ULC steels (transformation temperatures: LC [810-850°C], ELC [830-900°C], ULC [840-910°C]**
Slika 14. **Ovisnost naprezanja pri tečenju o temperaturi deformacije čelika LC, ELC, ULC (transformacija temperature: LC [810-850°C], ELC [830-900°C], ULC [840-910°C]**

- the strips are soft with $R_{P0.2} \leq 180$ after ferritic rolling and they show good plastic properties what results in the decrease of required rolling forces up to 20 % in the subsequent cold rolling;
- the strips are softer with higher ductility after ferritic rolling with subsequent continuous or batch annealing when compared to the classical rolling;
- the degree of deep-drawing on the level of CQ and DQ is achieved for ELC ferritic rolling steels while degrees DDQ and EDDQ can be attained for ULC steels and finally, SDDQ degree for SULC steels.

CONCLUSION

Based on the literature data as well as own experimental results it is possible to make the following conclusions concerning the future development in the production of steel sheets for automotive industry:

- decrease of total car weight will be achieved through decrease of weight of body, under cart and engine;
- research and development of the steels and rolling technologies is, starting from nineties, focused on:
  - BH steels, IF steels, TRIP steels, SULC and IZ steels;
  - controlled hot rolling and controlled cooling especially for the feritic rolling.

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