

# Plasticity Behavior of the Steel Depending on the Cooling Regimes in the Case of a Non-Conventional Treatments

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*Plasticity of the steel-as an important property of the material-has the role to show the capability of the steel to support plastic deformation necessary to obtain pieces for industry. Plasticity can be influenced by cooling regimes from higher temperatures in the cases of non-conventional treatments. An important factor is the cooling speed of the steel from higher temperatures during non-conventional treatment applied after lamination of the material. To modify the speed of the cooling, the medium of the cooling has been changed. The samples of the steel have been cooled in normal condition, in metallic box and using a jet of cold air. The evolution of the plasticity was studied taking in consideration the evolution of some characteristics. This paper might be considered as a review of the researches from the last years.*

**Keywords:** Steel, plasticity, cooling regime, non-conventional treatment

The plasticity of the steel depends on many factors. For example, it depends on deformability of the steel. According to the literature, the deformability of the steel characterizes the ability to be deformed permanently without breaking the inner linkages. Deformable metals and alloys and some types of steels can be considered elasto-plastic-viscous bodies [1, 2].

To study the plasticity of a steel with a low carbon content, must be considered the influence of the temperature which is an important factor influencing the physico-chemical state of the alloys. After deformation at higher temperature (lamination, for example), the speed of cooling modifies the properties of the plasticity of the steel by increasing and it is possible to appear micro-cracks in the structure, if this cooling speed isn't controlled very carefully.

In the Literature, Hanning's and Boulger's deformability variations depends on the temperature of the deformation. It can be seen that the temperature of deformability around (250 ... 300) °C is due to the formation of precipitates that

favor the fragility of the tempering to blue. The increasing rapidly of the deformability between 600 and 800 °C is due to inter-crystalline displacements and re-crystallization of steel. At the same time, the deformability of the steels depends on the carbon content [1-3, 5].

Studying the microstructure of steels with 0.1% C, 0.48% Mn, 0.24% Si the mechanical properties of the steels are influenced by the sizes and the shapes of pearlitic (P) and ferritic (F) grains which form its microstructure. Ferrite has a low mechanical strength but it has good plasticity properties. Cementite (Cem) in steels has a good hardness but it is fragile, that's why Cementite can cause cracks. Cementite can break the inner linkages. Therefore, with the increasing of the carbon content, the hardness and the strength of the steels increase and the plasticity properties decrease [1, 3, 5-9].

The steels with low carbon content have high plasticity properties below 550 °C and the thermal stresses will not leads to the formation of cracks [1].

**Table 1**  
SCHEME OF HOT LAMINATION OF STEEL SHEET

Nb. of passes	Type of rolling/ Passes/ crossing	Thick- ness [mm]	Width [mm]	Length [mm]	Absolute reduction ratio [mm]	Relative reduction ratio [%]	Reduction ratio coefficient $\gamma$	Obs.
0	-	150	1500	2500	-	-	-	-
1	Pressing by forging	150	1450	2600	-	-	-	Rotation 90°
2	Lamination on width	185	2600	1750	23	16.9	1.20	-
3	Lamination on width	105	2070	2090	20	16	1.19	-
4	Pressing by forging	105	2050	2620	-	-	-	Rotation 90°
5	Pressing by forging	105	2050	2650	-	-	-	-
6	Lamination on length	85	2050	3250	20	19	1.24	-
7	Lamination on length	65	2050	4200	20	23.5	1.30	-
8	Lamination on length	45	2050	6100	20	30.8	1.44	-
9	Lamination on length	30	2050	9200	15	33.5	1.50	-
10	Lamination on length	20	2050	13700	10	33.3	1.50	-
11	Lamination on length	14	2050	19600	6	30	1.43	-
12	Lamination on length	11	2050	25000	3	21.4	1.27	-
13	Lamination on length	10	2050	27500	1	9.1	1.10	-

The lamination Technology was realized according to EN 10025-2:2004.

The chemical composition of the steel was presented in Table 2 [1].

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Element	C	Mn	Si	Mo	P	S	Cu
Content [%]	0.14	1.51	0.31	0.009	0.01	0.01	0.18

**Table 2**  
CHEMICAL COMPOSITION OF THE STEEL

The paper focuses on directed fast cooled steels strips for automotive application after hot laminated process [3].

#### Lamination of large thickness sheets before non-conventional treatment

In table 1 was considered a scheme of hot lamination of steel sheet. The samples had the following dimensions: 10 x 150 x 200 mm and came from a slab with the dimensions: 150 x 1500 x 2500 mm. For a thick sheet rolling it is necessary to have one system type quarto (two pairs of rolls - four Rollers Cylinders), with a sheet width maximum of 3000 mm and a vertical rolling system, placed in front of the first system. The hot lamination scheme is shown in table 1 [1].

#### Experimental part

Twelve experiments have been carried out - considering three groups of samples and each group supported three types of non-conventional treatments, taking in consideration four values of the initial temperatures.

There were considered three groups of samples of steel and each group had four samples.

The samples were heating at the different temperatures: T1 = 850°C (for the first batch of samples), T2 = 900°C (for the second batch of samples), T3 = 950°C (for the third batch of samples) and T4 = 1000°C (for the last batch of samples). Three cooling regimes [1, 3] have been used: (1) cooling regime in normal conditions; (2) cooling regime in metallic box; (3) cooling in air flow (using a jet of cold air). If the cooling mediums differ, the speeds of the cooling differ too.

Traction tests at the room temperature were carried out according to ASTM: E8M-11 standard [1, 3, 17], while those related to elevated temperatures were carried out according to ASTM: E21-09 [1, 3, 5, 10, 14, 16]. Charpy impact tests for resilience determination were carried out according to ASTM: E23-07ae1 standard [11]. The preparation of metallographic specimens was conducted according to ASTM E3-11 standard [1, 3, 6, 8, 12-15, 18]. All of mentioned standards can be found in Annual Book of ASTM Standards (2012) [1].

#### Results and discussions

In table 3, the cooling speed values for each different cooling conditions influences the mechanical properties of the steel. The results obtained after the experimental scheme [1, 3] have been presented.

Cooling Speed value (VR) - Average [°C/min] was calculated with the following relation [1, 3, 5, 14]:

Cooling Conditions	Initial temperature [°C]	KV <sub>-20</sub> (-20°C)	Cooling Speed values (VR) - Average [°C/min]	KV <sub>+20</sub> (20°C)	A5 [%]	σ <sub>c</sub> (RC) [N/mm <sup>2</sup> ]
(1)	1000	73	5.03	93.5	35	385
(1)	950	83	6.20	91	34.2	386.5
(1)	900	80	6.82	87.5	43	396
(1)	850	61	7.35	81	32.5	406
(2)	1000	76	3.69	94.5	35.3	377
(2)	950	69	3.88	85.5	34	396
(2)	900	65	4.15	88	36.8	392
(2)	850	75	4.61	89	35.8	393
(3)	1000	56.5	19.62	98	33.8	367
(3)	950	66	20.21	96	34.8	440
(3)	900	85	20.95	98	33.8	390
(3)	850	77	21.84	90	33.2	391

**Table 3**  
MECHANICAL PROPERTIES OF THE STEEL ACCORDING TO THE COOLING SPEED

Cooling Speed value (VR) - Average [°C/min] was calculated with the following relation [1, 3, 5, 14]:

$$VR = (t - t_0) / \Delta\tau, [\text{°C/min.}] \quad (1)$$

where t = the initial temperature corresponding to each cooling regime, [°C]; t<sub>0</sub> = the final temperature which was approximate to 20°C; Δτ = the cooling duration, [min.].

Flow Limit or High Deformation Limit is very important for steels used for metal construction or for armatures. The resistance of the metallic bridge or the resistance of the wall in construction depends on the flow limit of the steel with a low content of Carbon.

In figures 1 to 3, the evolution of the Flow Limit depending on the cooling speed from the initial temperature corresponding to the steel analyzed, have been presented.

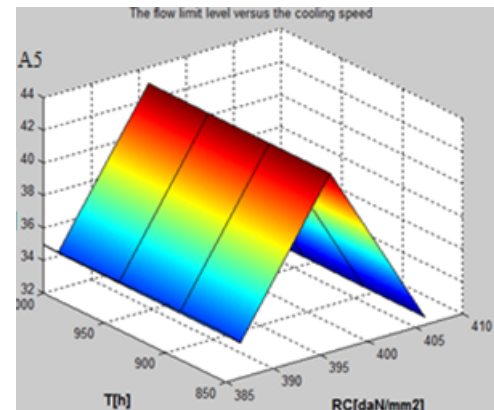


Fig. 1. The evolution of the Flow Limit (RC) and the elongation at break (A5) depending on the initial temperature (T), for cooling in normal conditions

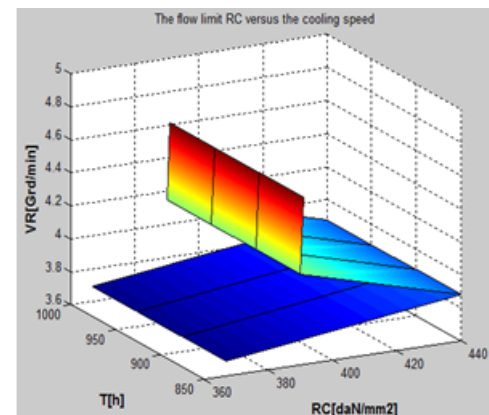


Fig. 2. The evolution of the Flow Limit (RC) depending on the cooling speed (VR) from the initial temperature, for cooling in metallic box

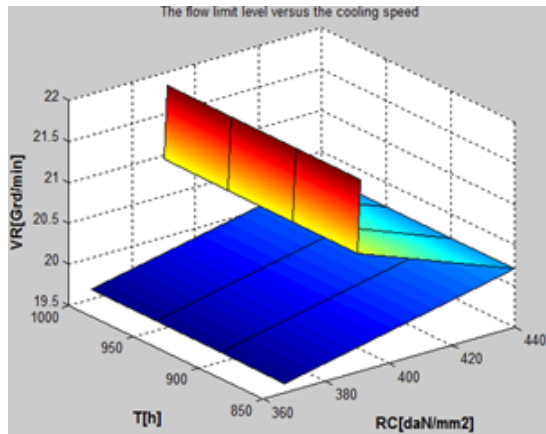


Fig. 3. The evolution of the Flow Limit (RC) depending on the cooling speed (VR) from the initial temperature, for cooling in cold jet of air

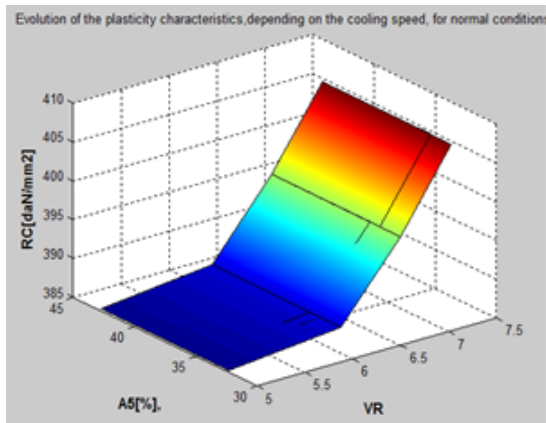


Fig. 4. Evolution of the Elongation (A5) and Flow Limit (RC), depending on cooling speed, for normal conditions

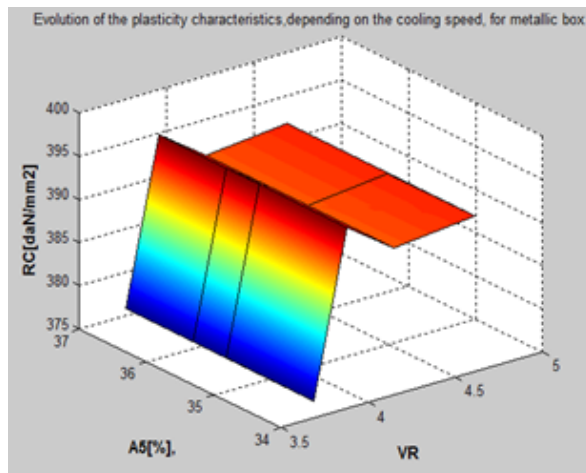


Fig. 5. Evolution of the Elongation (A5) and the Flow Limit (RC) depending on cooling speed, for cooling in metallic box

When the steel is cooling in a metal box, the cooling rate is very low. A good resilience measured at  $-20^{\circ}\text{C}$  was obtained when cooling under normal conditions from  $850^{\circ}\text{C}$ . A good stretch has been achieved by cooling in a metal box, especially from an initial temperature of  $1000^{\circ}\text{C}$ . However, its value is lower than that of cooling under normal conditions.

A very good Flow Limit of steel was obtained by cooling in a cool air jet from the initial temperature of  $850^{\circ}\text{C}$ . Therefore, a quick cooling in cold air jet from an initial temperature of  $850^{\circ}\text{C}$  is recommended for obtaining an optimum flow limit, improving the resistance of steel to plastic deformation. The behavior of steel in the case of plastic deformation is the best when the steel is heated at

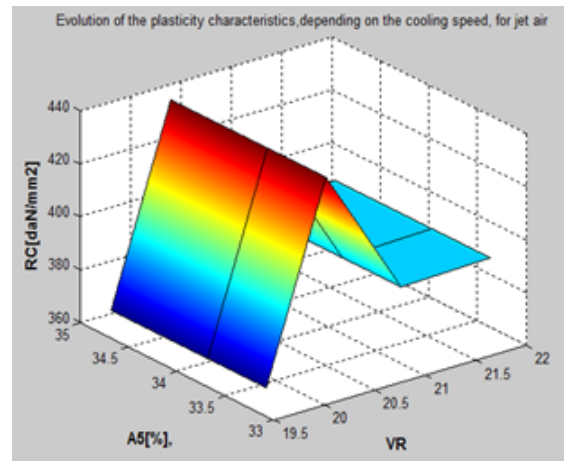


Fig. 6. Evolution of the Elongation (A5) and the Flow Limit (RC) depending on cooling speed, for cooling in cold jet of air

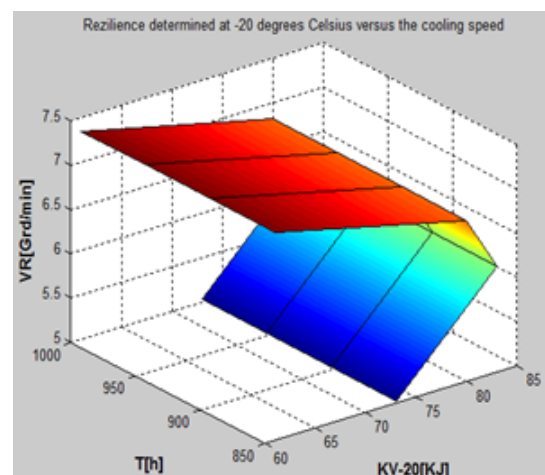


Fig. 7. Resilience (KV) determined at  $-20^{\circ}\text{C}$  depending on the cooling speed (VR) in the case of the cooling in normal conditions

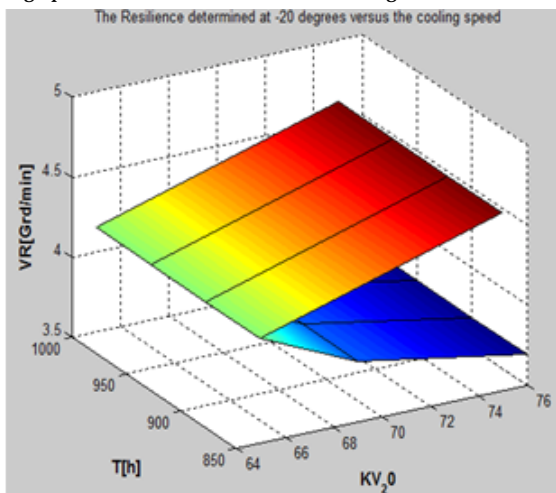


Fig. 8. Resilience (KV) determined at  $-20^{\circ}\text{C}$  depending on the cooling speed (VR) in the case of the cooling in metallic box

$850^{\circ}\text{C}$  after hot rolling and it is cooled in cold air jet, the cooling rate being very high.

If the samples are cooling in a metallic box from an initial temperature of  $1000^{\circ}\text{C}$ , a good resilience is obtained, measured at ambient temperature ( $+20^{\circ}\text{C}$ ).

The temperature of the rolling of steel influences the characteristics of the steel. If it is applied a heating after lamination and it is studied the influence of the speed of cooling on some characteristics of that steel, it can be obtained changes of the plasticity evolution.

A fine structure of the hot-laminated steel is observed in the case of the cooling in metallic recipient (box) and in



the case of the cooling in cold jet of air. The basic structure is compound by Ferrite (F) and lamellae of Pearlite (P). The micro-structures in strings are specific to laminated structures. Manganese (Mn) content more than 2.75% determines the increasing of the tenacity and plasticity of the steel, comparing to simple casted steel.

## Conclusions

The flowing limit - the highest value - was obtained in the case of the cooling in cold jet air, especially in the case of the cooling from 950°C. In all cases, a high Flow limits were recorded at the cooling in jet of air from the temperatures of 950, 900 and 850°C. After non-conventional heating process and cooling in different mediums, the steel flowing limits have exceeded the values of the same steel after hot lamination ( $\sigma_c = 360 \text{ daN/mm}^2$ ).

The lowest resilience value determined at negative temperatures (-20°C) was recorded for air-jet cooling from 1000°C. The resilience represents the tenacity of the steel. A good tenacity represents a good plasticity of the steel.

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