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Professional paper

EFFECT OF COOLING PARAMETERS ON TENSILE PROPERTIES OF CONCRETE REINFORCING STEEL IN COILS

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ABSTRACT

The production of concrete structural steel using controlled cooling with Tempcore technology enables the production of high-strength steel with improved adhesion to concrete while ensuring homogeneous properties for the construction of buildings, bridges, highways, and other construction facilities in any geographical environment. Concrete reinforcing steel can be produced in the form of bars or coils. The production of concrete reinforcing steel in coils ensures higher productivity, increased output, lower labor costs, and faster application.

When producing concrete reinforcing steel in coils, achieving the required tensile properties cannot be accomplished solely by cooling it with water in the Tempcore plant. Additional cooling in separate water boxes is necessary before coiling the steel. By varying the cooling parameters in the Tempcore plant and additional water boxes, it is possible to control and optimize the strength and ductility properties of the concrete reinforcing steel in the coil. In the scope of this paper, the optimal ratio of strength and ductile properties is achieved by applying cooling parameters according to cooling variant II.

Keywords: concrete reinforcing steel, Tempcore process, coiled rebar, tensile test

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1. INTRODUCTION

Concrete is a brittle material having remarkable compressive strength but much lower tensile strength [1,2]. This is disadvantageous especially in the case when the concrete part is loaded in bending. On side of such concrete part, on which bending force acts, compressive stress appears and tensile stress on opposite side. Since concrete is weak in tension, it is prone to cracking and failure. Brittle fracture of concrete can be prevented by reinforcing with steel bars, because steel, in addition to its ductility, shows excellent strength both under tension and under pressure.

Steel for the concrete reinforcing is required to have a high yield stress, good weldability and ductility. Previously, these steels were produced by microalloying with Nb and V, which is expensive, or by applying cold deformation, which required additional processing, which also increases production costs. To avoid the drawback of these methods, in 1975 C.R.M. Liege, Belgium installed the first industrial Tempcore system, which enabled the improvement of steel quality and reduction of production costs of the concrete reinforcing steel [3,4]. Since the beginning of the eighties, Tempcore process has become an absolute must to produce weldable high strength reinforcing bars at low-cost. Thus, this process has been introduced in hundreds of rolling mills, directly at the exit of their finishing stands [5].

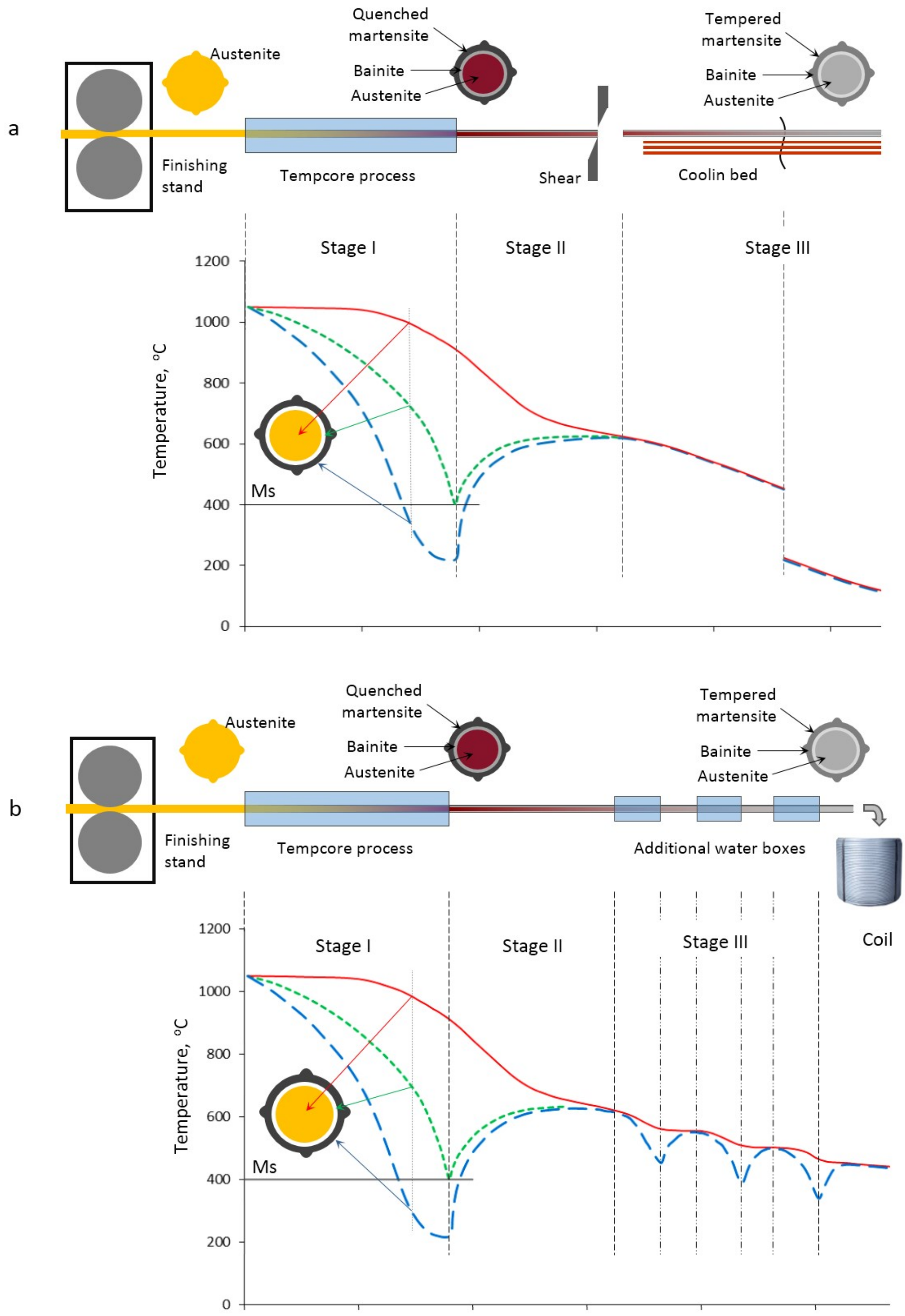

Figure 1. The general production scheme of the concrete reinforcing steel in bars (a) and coils (b)

The process of manufacturing concrete structural steel using controlled cooling with Tempcore technology enables the production of high-strength steel with improved adhesion to concrete, while ensuring homogeneous properties for the construction of buildings, bridges, highways and other construction facilities in any geographical environment. The production of concrete reinforcing steel (rebar), including the Tempcore process, involves three stages, as shown in Figure 1. In the first stage, after leaving the last stand of the hot rolling mill, the rebar goes through the Tempcore plant, which has a special water cooling system. In this plant, a surface layer of the rebar is quenched into martensite, while the core remains austenitic. The thickness of the martensite layer or the thickness of the rebar's surface layer where the temperature drops below the M_s temperature is depended on cooling intensity.

In the second stage, the temperature of the surface and center of the rebar are equalized because the temperature gradient established in the first stage in the rebar cross-section causes heat transfer from its center to the surface. The rise in temperature of the surface layer leads to the self-tempering of the martensite. In the third stage, during the slow cooling of the rebar, the austenitic core transforms into ferrite and perlite.

In the production of concrete reinforcing steel, the final cooling process differs depending on its form. For reinforcing steel bars (see Figure 1a), the final cooling occurs in the air on a cooling bed. For concrete reinforcing steel produced in coils (see Figure 1b), the final cooling occurs in extra water boxes placed before the winding process. After the coils are formed into compact shapes, they undergo air cooling. Manufacturing concrete reinforcing steel in coils increases productivity, boosts output, reduces labor costs, and enables quicker application.

The bars of the concrete reinforcing steel that are cooled on the cooling bed are separated from each other and will cool faster than the concrete reinforcing steel in the coil. Consequently, the conditions for phase transformations in concrete reinforcing steel vary depending on the shapes. Additional water boxes, Figure 1b, should ensure sufficient temperature reduction of the concrete reinforcing steel before coiling to achieve the required mechanical properties according to the relevant product standards. In this paper, we investigate how Tempcore plant parameters and additional water boxes influence the tensile properties of concrete reinforcing steel.

2. EXPERIMENTAL RESEARCH AND TEST RESULTS

2.1 Practical work

Continuously cast billets with dimensions of 150x150x12000 mm were used to produce concrete reinforcing steel B500B in both bar and coil shapes. Hot rolling of continuous casted billets to the final diameter of 14 mm was carried out on the Bar Mill of ArcelorMittal Zenica. The chemical composition of the melts used for bar production is presented in Table 1, while the chemical composition of the melts used for the coils is presented in Table 2. Corresponding C equivalents (C_{eq}) have been calculated according to standard BAS EN 10080:2007 [6]. The chemical compositions and corresponding C equivalents of the melts used are very similar, and the differences between them should not impact the ability to achieve the required tensile properties. Therefore, achieving the required tensile properties of the concrete reinforcing steel in bars and coils mostly depends on its cooling rate after leaving the last stand.

The cooling parameters in the Tempcore plant for the production of the concrete reinforcing steel in a bar with a diameter of 14 mm ensure the achievement of satisfactory tensile properties for steel B500B according to standard SRPS EN 10080:2008 [7], Table 3. The cooling parameters in the Tempcore plant and the additional water boxes for the production of concrete reinforcing steel B500B in coils with a diameter of 14 mm are presented in Table 4.

Table 1. The chemical composition of the melts used for rolling bars with a diameter of 14 mm

Melt	Chemical composition (wt. %)					
	C	Si	Mn	P	S	C_{eq}
Melt A	0.17	0.12	0.55	0.043	0.015	0.27
Melt B	0.18	0.12	0.56	0.027	0.008	0.28

Table 2. The Chemical composition of the melts used for rolling of coils with a diameter of 14 mm

Melt	Chemical composition (wt. %)					
	C	Si	Mn	P	S	C_{eq}
Melt 1	0.18	0.11	0.52	0.023	0.021	0.28
Melt 2	0.18	0.10	0.51	0.026	0.014	0.28
Melt 3	0.18	0.11	0.50	0.021	0.009	0.27
Melt 4	0.19	0.12	0.56	0.040	0.019	0.29

Table 3. Cooling parameters in the Tempcore plant for the production of the concrete reinforcing steel in a bar with a diameter of 14 mm and the achieved tensile properties

Melt	Order number of the test piece	Rolling speed (m/s)	Tempcore process			Time of cooling on the cooling bed	Proof strength $R_{p0.2}$ (N/mm²)	Tensile strength R_m (N/mm²)	R_m/ $R_{p0.2}$	A_{gt} (%)
			Water flow (m³/h)	Water pressure (bar)	Tempering temperature (°C)					
B500B[1)]	-	-	-	-	-	-	500-650	≥ 540	≥1.08	≥5.0
Melt A	1	15.2	540	11.7	590	6 min.	557	649	1.17	8.8
	2						550	648	1.18	8.4
	3						553	649	1.18	8.2
Melt B	1						554	652	1.18	8.6
	2						559	651	1.16	8.4
	3						555	650	1.17	8.3

Note: [1)] according to standard SRPS EN 10080:2008

Continuously cast billets from four melts were used to produce concrete reinforcing steel in coils. The same cooling parameters were used for melts 1 and 2, while the other melts (melts 3 and melts 4) were cooled with different parameters. This means that three different cooling variants were applied. The front and rear ends of the rolled bars, before coiling, were cooled to a higher temperature than the middle part of the bars because the inner and outer parts of the coils cooled faster than their middle part. The change in surface temperature of the hot rolled bars and coils, including cooling in the Tempcor plant and additional water boxes, as well as during coils cooling, for variant II is shown in Figure 2. Additional water box No. 1 was not used.

The tensile properties of the concrete reinforcing steel produced in coils are presented in Table 5. Test samples were taken from different coils produced from the same melt.

Table 4. Cooling parameters in the Tempcore plant and additional water boxes for the production of the concrete reinforcing steel in the coil with a diameter of 14 mm

Melt	Rolling speed (m/s)	Cooling variant	Tempcore process			Additional water boxes			Time of cooling to the room temperature
			Water flow (m^3/h)	Water pressure (bar)	Tempering temperature (°C)	Part of the rolled bar	Water pressure (bar)	Temperature (°C)	
Melt 1 Melt 2	15.2	I	563	10.5	560	Front end	4.2	530	Approx. 24 hours
						Middle	3.8	500	
						Rear end	4.2	520	
Melt 3	15.5	II	500	9.7	580	Front end	4.3	475	
						Middle	4.0	450	
						Rear end	4.1	480	
Melt 4	15.5	III	480	8.4	600	Front end	4.8	460	
						Middle	4.5	430	
						Rear end	4.7	460	

Table 5. Tensile properties of the concrete reinforcing steel in the coil with a diameter of 14 mm

Steel/ Melt	Cooling variant	The number of coils from the melts	0.2% proof strength $R_{p0.2}$ (N/mm^2)	Tensile strength R_m (N/mm^2)	$R_m/R_{p0.2}$	Percentage total elongation at maximum force A_{gt}
B500B[1)]	-	-	500 - 650	≥ 540	≥ 1.08	≥ 5.0
Melt 1	I	3	470	708	1.51	9.30
		20	480	700	1.46	11.30
		50	486	685	1.38	10.90
Melt 2		2	437	687	1.57	12.00
		15	440	701	1.59	10.40
		50	435	704	1.66	10.60
Melt 3	II	10	549	679	1.24	8.20
		20	547	676	1.24	8.90
		34	547	680	1.24	8.50
		50	542	681	1.26	7.30
Melt 4	III	7	567	719	1.27	7.50
		15	578	717	1.24	7.70
		27	576	718	1.25	7.80
		50	563	717	1.27	6.50

Note: [1)] according to standard SRPS EN 10080:2008

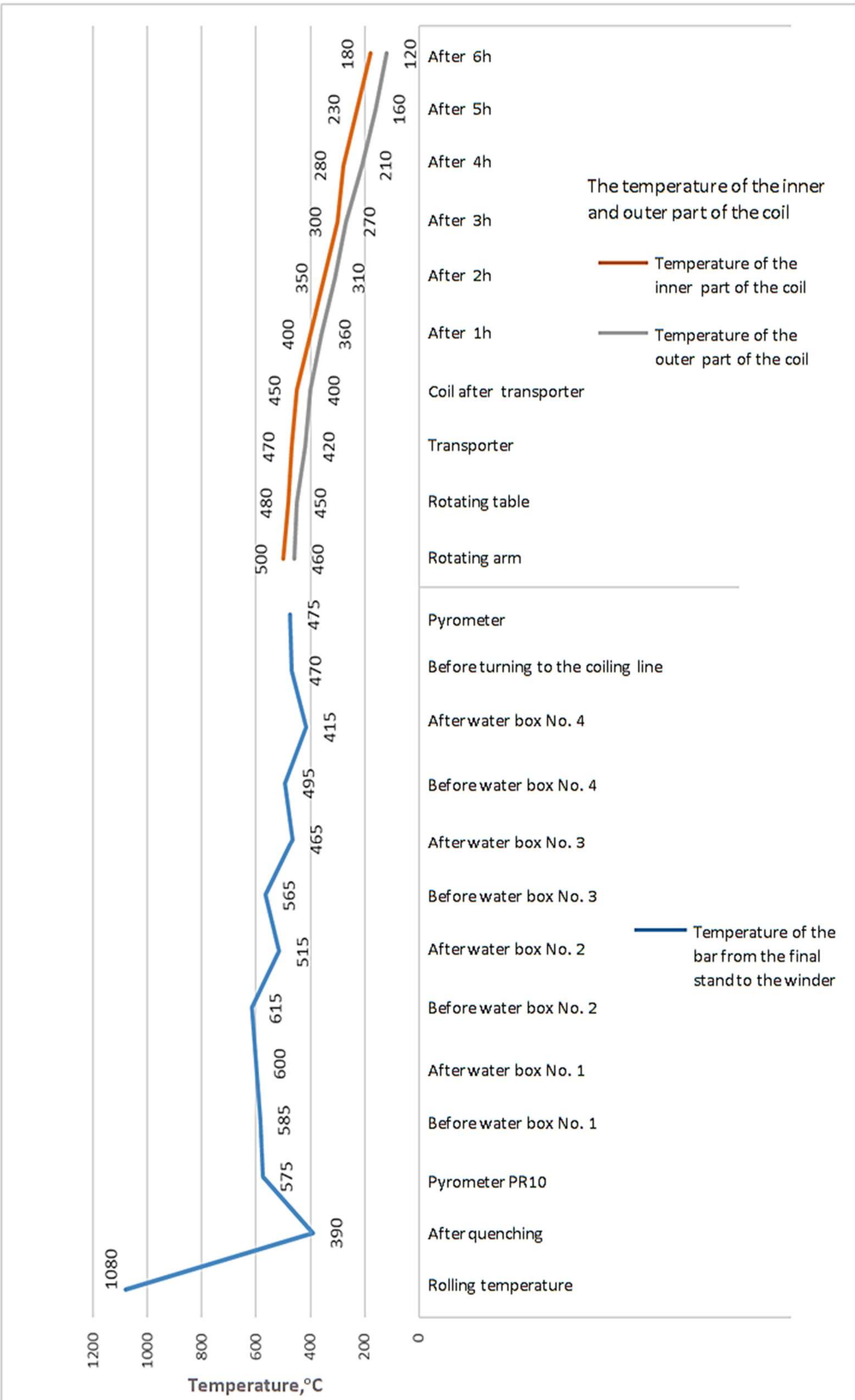

Figure 2. The change in surface temperature of hot rolled bars and coils, including cooling in Tempcor plant and additional water boxes as well as during cooling of coils for variant II

2.2 Discussion

The cooling parameters at the Tempcore plant for producing concrete reinforcing steel bars ensure that the required tensile properties are achieved, Table 3. Adjusting the cooling parameters at the Tempcore plant alone does not achieve the required tensile properties for concrete reinforcing steel in coils. The main reason is related to the cooling conditions in the production of the concrete steel in the form of bars and coils. The total cooling time of the bars on the cooling bed is approximately 6 minutes, while the total cooling time of the coils to room temperature is approximately 24 hours. The bars of the concrete reinforcing steel on the cooling bed are separated from each other, so the surface from which the heat is transferred to the environment is larger, and thus the cooling is faster. In the case of coiled steel, the individual coils are in contact with each other, whereby a large mass of steel is packed into a relatively small volume. Due to slower cooling, concrete reinforcing steel in coils is kept at higher temperatures longer, so tempering (softening) processes take longer.

When producing concrete steel in coils, it is insufficient to adjust only the cooling parameters in the Tempcore plant to achieve the required tensile properties. Instead, a more drastic quenching process would need to be employed. This is not possible because the intensity of cooling in the Tempcore plant is adjusted to the thickness of the surface martensitic layer that needs to be achieved. Additional water boxes are required for extra water cooling before coiling the steel into a coil. The cooling parameters at the Tempcore plant should ensure the achievement of the surface martensite layer with required thickness, while the additional water cooling at the additional water boxes should ensure a sufficient lowering of the temperature of the steel before coiling in order to avoid excessive softening of the steel during its cooling in the compact coil.

More intense cooling on the Tempcore plant and less intense cooling on the additional water boxes (Cooling variant I - Table 4) does not allow achieving the required tensile properties, i.e. 0.2% proof strength of steel the B500B, Table 5. Less intensive cooling on the Tempcore plant and more intensive cooling on additional water boxes (Cooling Variant II - Table 4) enables achieving the required tensile properties of the steel B500B, Table 5. A further reduction of the cooling intensity in the Tempcore plant with an increase of the cooling intensity on the additional water boxes (Cooling Variant III - table 4) also allows for achieving the required tensile properties of the steel B500B, Table 5, but with increased values of 0.2% proof strength and tensile strength with the decrease in the value of percentage total elongation at maximum force.

3. CONCLUSION

The required tensile properties of concrete reinforcing steel in bars can be achieved by the correct choice of cooling parameters on the Tempcore plant with final cooling on the cooling bed. On the other hand, the required tensile properties of concrete reinforcing steel in coils cannot be achieved only by adjusting the cooling parameters in the Tempcore plant, with final cooling of the coils in still air, without additional cooling in additional water boxes, before its coiling. Increased cooling intensity at the Tempcore plant, coupled with reduced cooling in additional water boxes, does not guarantee the attainment of the required tensile characteristics, particularly the 0.2% proof strength of the steel coils. Lowering the cooling intensity on the Tempcore plant while increasing it on additional water boxes ensures that the required tensile properties of the steel in coils are achieved. Further reducing the cooling intensity in the Tempcore plant, while increasing the cooling intensity in the additional water boxes, results in an unnecessary increase in strength and a decrease in ductility. Optimal cooling parameters for the Tempcore plant and additional water boxes can be selected. In the scope of this paper, those are the cooling parameters according to cooling variant II.

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Conflicts of Interest

The authors declare no conflict of interest.

4. REFERENCES

[1] A. S. Savinykh, G. V. Garkushin, G. I. Kanel, S. V. Razorenov, Compressive and tensile strength of steel fibrous reinforced concrete under explosive loading, *Int. J. Fract.,* (2019) 215:129–138, https://doi.org/10.1007/s10704-018-00342-w

[2] X. Zhou, The application and development of reinforced concrete structure in building construction. *Journal of Materials, Processing and Design,* 7(2023) 3, DOI: 10.23977/jmpd.2023.070302, ISSN 2516-0923

[3] G. Rehm, D. Russwurm, Assessment of Concrete Reinforcing Bars made by the Tempcore Process; CRM *Revue*, (1977) 51, pp. 3-16

[4] P. Simon, M. Economopoulos, P. Nilles, Tempcore: A new process for the production of high-quality reinforcing bars, *Iron Steel Eng.*, (1984) 61, pp. 53–57

[5] J. F. Noville, TEMPCORE®, the most convenient process to produce low-cost high strength rebars from 8 to 75 mm, METEC & 2nd ESTAD, Düsseldorf, 15 – 19 June 2015

[6] Institut za standardizaciju Bosne i Hercegovine BAS, BAS EN 10080:2007, Čelik za armiranje betona - Zavarivi armaturni čelik - Općenito, Istočno Sarajevo: BAS 2007

[7] Institut for standardization of Serbia SRP, SRPS EN 10080:2008, Steel for the reinforcement of concrete - Weldable reinforcing steel – General, Belgrade: SRP 2008