Investigation of The Effect of Rolling Speed-Water Flow Quantity Relationship on Tensile Properties of Concrete Steel in Tempcore Cooling Method

Özgür Galip Dikbaş[1], Bilge Demir[2]

1. *KBU, Faculty of Engineering, Mechanical Eng. Dept., Karabuk/TURKEY*
   ozgur_dkbs@hotmail.com
2. *Mechanical Eng. Dept., Karabuk University Karabuk/TURKEY*
   bdemir@karabuk.edu.tr

Abstract—**The earthquake known as August 17 for the durable building material concept in our country has been an important turning point. After this date, Turkey has entered the building sector as well as an enriched profile and more durable steel construction process for the construction of the use of steel reinforcement materials with legal regulations. Over time, it has reached its current strong quality by showing significant improvements in both alloy and process. Today, construction steels; It is produced with ribbed and tempcore process. At this point, steels with low carbon and tempcore process are used in the cooling phase. Therefore, it is important to understand and manage the characteristic material content and especially the effect of the tempcore process on the properties of these steel bars. In this study, from the year 2019 in Turkey permitted to be used by law as a single quality B420C low-carbon concrete steel was examined relation between the most appropriate manufacturing method tempcore the production methods used in the cooling water flow and the rolling speed.**

Keywords— **Tempcore Process, Construction-Concrete Steel, Cooling Regime, Roll Outlet Temperature, B420C Quality**

I. INTRODUCTION

For weldable reinforced concrete steels that have been produced in large quantities in recent years, quenching and self-tempering of the steel bar has become a very popular solution. Tempcore process is a high strength steel production method registered with the Belgian patent number 790.867 dated 30.10.1972 [1].

The biggest advantage of this material; It is hard outside, soft inside and has high yield strength. Since its elastic zone is wide, it does not lose its elasticity up to 550 N / mm2 and its tensile strength increases up to 650 N / mm2. This technology is used in Turkey since the early 1990s rebar produced by the method tempcor are exported to countries all over the world [2].

The most important mechanical property required in reinforced concrete steel bars is high yield strength. Carbon is the most important alloying element that provides high yield strength in steel. The higher the amount of carbon in the steel, the higher the yield strength. However, the amount of carbon used is important to obtain high yield strength. Because the high amount of carbon affects the weldability and elasticity of the steel negatively. Therefore, it is another important element that is desired to produce with low C amount in reinforced concrete steel bars. However, low carbon content causes low yield strength. It is very difficult and costly to obtain high yield strength by processing low-carbon raw materials with traditional production methods. Low carbon reinforced concrete steel bars produced by conventional production do not show enough strength increase after rolling. Therefore, additional processing is required. These processes are thermal processes combined with rolling mill. This system is the Tempcore process.

In the Tempcore system (Fig.1), hot-rolled ribbed steel bars take the form of ribs from the last rolling stand, and after entering into a water-cooled machine called tempcore, the outer surface of the ribbed steel bar is cooled for a short time and a martensite layer is formed. After the ribbed steel bar leaves the tempcore system, the outer surface is martensite, the core part is ferrite-pearlite or ferrite-pearlite and bainite. Tempering process is required because martensite formed on the outer surface is very hard. In order to achieve this, it is necessary to apply a heat treatment to the ribbed steel bars after production. But doing this is very difficult and very costly. However, the core part of the reinforced concrete ribbed steel bars coming out of the tempcore system is still hot. When this temperature is combined with the heat of the other ribbed steel rods adjacent to the cooling platform, martensite will reach the tempering temperature, so martensite is tempered without the need for additional processing.

In this way, the outer surface of the reinforced concrete ribbed steel bar is tempered martensite, and the core is in ferrite-pearlite or ferrite-pearlite and bainite structure. In addition to the required strength in reinforced concrete steel bars of this structure, it meets the expectations of ductility, toughness, bendability, and weldability.

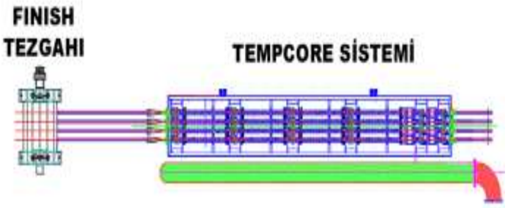

Fig. 1. Finishing Stand and Tempcore System [5]

As a matter of fact, in many modern countries and international concrete steel standards, the defined grades are taken with a symbol containing the yield strength value.

Table 1. Reinforced Concrete Steel Production Standards [8]

Standard	**Standard Code**	**Yield Strength**
TSE 708/2010	S420	min 420 MPa
TBDY/2018	B420C	min 420 MPa
DIN 488	BSt 500S	min 500 MPa
BS 4449	Gr 460B	min 460 MPa
AS 1302	400Y	min 500 MPa
ENV10080	B500B	min 500 MPa
NEN 6008	FeB500	min 500 MPa
NS 3570	K500TE	min 500 MPa

	Çelik sınıfı						
	S220 Düz	S420 Nervürlü	B420B Nervürlü	B420C Nervürlü	B500B Nervürlü	B500C Nervürlü	B500A Profilli
Akma dayanımı $f_{yk}=R_e$ (N/mm²)	≥220	≥420	≥420	≥420	≥500	≥500	≥500
Çekme dayanımı $f_{su}=R_m$ (N/mm²)	≥340	≥500	-	-	-	-	≥550
Çekme dayanımı/akma dayanımı oranı $f_{su}/f_{yk}=R_m/R_e$	≥1.2	≥1.15	≥1.08	≥1.15 <1.35	≥1.08	≥1.15 <1.35	-
Deneysel akma dayanımı/karakteristik akma dayanımı oranı $R_{e,act}/R_{e,nom}$	-	≤1.3	-	≤1.3	-	≤1.3	-
Kopma uzaması $\varepsilon_{su}=A_5$	≥%18	≥%10	≥%12	≥%12	≥%12	≥%12	≥%5
Maksimum yükte toplam uzama A_{gt}	-	-	≥%5	≥%7.5	≥%5	≥%7.5	≥%2.5
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Fig. 2. Mechanical properties of ribbed construction steel production standard according to TBDY [7]

1.1. TEMPCORE OPERATING PROCESS

The Tempcore cooling system is formed by the combination of many interconnected equipment. These; quenching line

- Cooling Mechanisms
- Water Collection and Return System
- Control System
- Cooling Water Hardware
- Cooling Towers
- Pumps
- Filters
- Piping

Fig. 3.Tempcore Cooling System [5]

These systems and the conditions of the rolling mill where the tempcore system will be included must be properly synchronized. The two most important factors in the conditions of the rolling mill;

- Tempering
- Final Rolling Speed

Annealing, tolerance ranges of raw materials exit temperatures from the annealing furnace are limited due to the tempcore system. Because the water flow rate in the tempcore system is adjusted according to the fixed annealing temperature in the annealing furnace. Therefore, the tolerance amount of the raw material with annealing temperature of 1250 ° C is around ± 30 ° C at most. Another important factor is the final mill exit speed. In other words, the exit speed of the final product coming out of the finishing counter is the most important factor for homogeneous cooling in the tempcore system. Depending on the outlet speed, the cooling water flow rate varies. The exit speed from the finishing counter determines the contact time of the final product with water. Increasing the contact time of reinforced concrete steels with water increases the thickness of martensite. Martensite adds strength to reinforced concrete steels. However, the increase in martensite thickness also causes brittleness in steel. The increase in the percentage of the martensitic structured area of reinforced concrete steel bars produced according to the Tempcore process increases the yield and tensile strength of the bar and decreases the% elongation value.[9] As a result, the ductility property expected from reinforced concrete steels is adversely affected. Therefore, the contact time of reinforced concrete steels with water is within a certain limitation. Likewise, the thickness of martensite formed in reinforced concrete steels with less contact time with water is low, so a reinforced concrete steel with high ductility but lower than the desired values in terms of strength is obtained.[3] In Figure 4 a and b, the length of the cooling stage and the water, ıt has been shown that the yield strength increases depending on the flow rate [6].

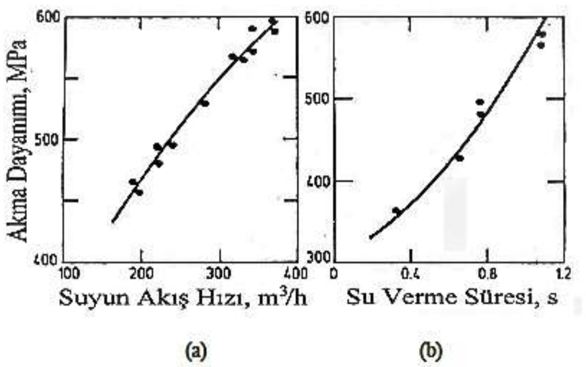

Fig.4 (a) Water Flow Rate and (b) Variation of Yield Strength With Quenching Rate [6]

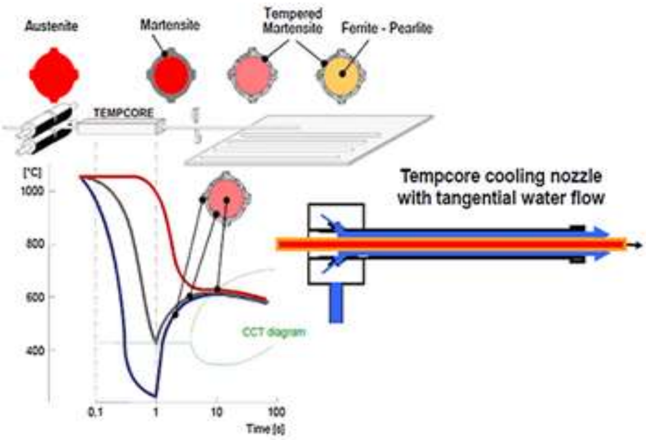

Fig. 5. Profile temperatures and microstructural changes of reinforced concrete steel produced with Tempcore at different stages [4]

As explained above, the relationship between the rolling speed and cooling water flow rate in the tempcore process is very important on the strength and other properties of concrete steels. Therefore, a commercial concrete steel quality and sector work were tried to reveal these properties, and commercially important technical data were produced.

II. EXPERIMENTAL STUDIES

In this study, steel billet-raw material with chemical composition specified in Table 2 was used.

Table 2.Chemical composition of steel raw material used in Tempcore system

Standard	Production Method	C	Mn	Si	Cr	S	Mo	Ni
TSE 708	Continuous Casting	0,18	0,55	0,15	0,54	0,025	0,007	0,042

The Ms temperature of this material is calculated as 440°C. Four different rolling speeds and four different cooling water flow rates were used in the study.

Equations used for the calculation of rolling speed and martensitic transformation starting temperature are given below;

Rolling speed;

$$V_{Roll} = \frac{(n.\prod.2r)}{60000}$$

V_{Roll} = Roll Output Speed

n = Roller Speed

It is calculated from the formula r = Roll Radius.

Ms temperature equation;

Ms = 539 – 423C – 30,4Mn – 17,7Ni – 12,1Cr – 11Si – 7Mo

Four different tensile tests were performed for each sample group and the average values of these values were taken.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The effect of the rolling speed on the cooling flow rate in the tempcore system as shown in Figure 6, the higher the rolling speed, the higher the cooling water flow rate.

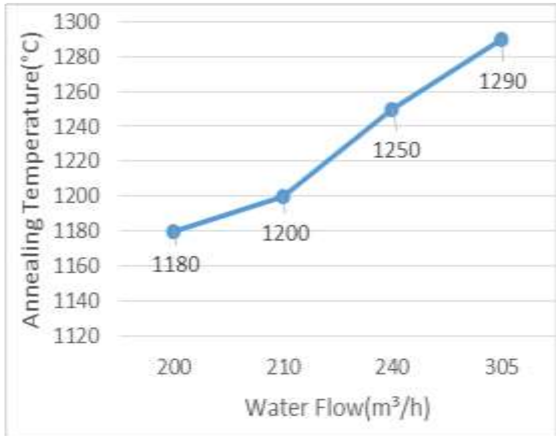

Fig. 6. Flow-Tensile Strength Graph Proportional to Changing Annealing Temperature and Flow Rate

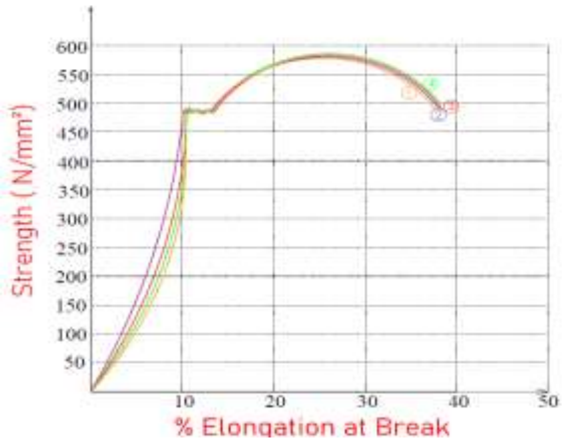

Fig. 7. Tensile Graph of Reinforced Concrete Steels Produced at Different Annealing Temperature

In the graphic shown in Figure 7, the effects of steel raw materials produced at different annealing temperatures on the water flow rate while passing through the tempcore system are shown. Figure 7 shows the tensile test results of the reinforced concrete steel produced at these flow rates. The reason why their yield strength is between 480 MPa and 490 MPa despite changing water flow rates is due to different annealing temperatures.

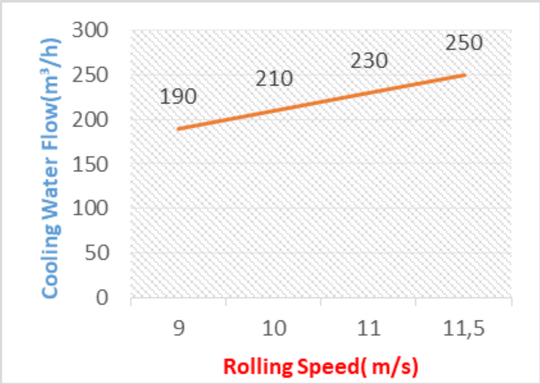

Fig. 8.The Effect of Increasing Rolling Speed on the Cooling Water Flow in Seconds

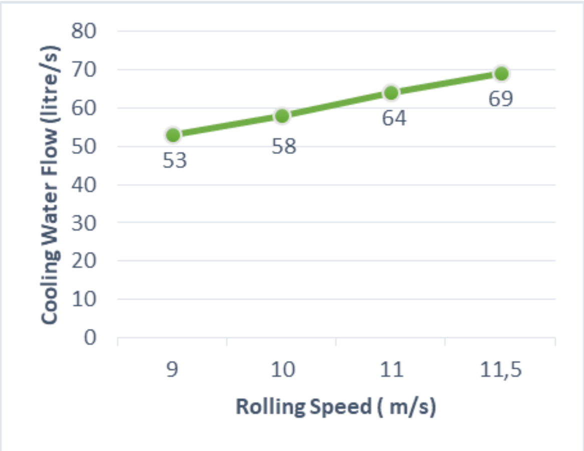

Fig. 9.Rolling Speed and Water Delivery Amount per Second

The reinforced concrete steel with a diameter of Ø8 mm with a rolling speed of 10 m / s gave the test result at a cooling water temperature of 20 ° C, a water flow rate of 230 m³ / h and a yield strength value of 470 MPa. When the rolling speed was increased by 1 m / s, the yield strength value of 470 MPa at the same cooling water flow at the same cooling water temperature was 455 MPa. When the rolling speed increased by 1 m / s, an increase of 5 liters per second, 300 liters per minute and 1800 liters per hour was observed in the cooling water flow. With the increase in the rolling speed, the value of the yield strength did not change much with the increase in the cooling water flow rate. The graph shown in Figure 10 are the tensile test results of four samples. Each of these four samples are in different rolling speed and cooling water flow rates. However, as seen in the graphic, there is not much difference between them in yield strength. Because, due to the relation between the rolling speed and cooling water flow rate, the flow rate can be determined by the change in speed and the yield strength can be kept constant.

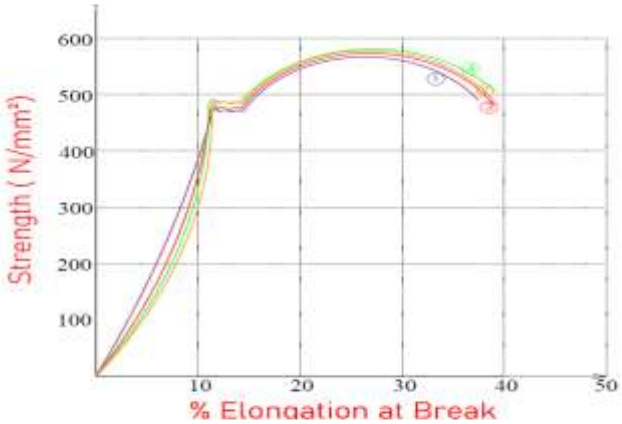

Fig. 10. Yield strength graph at different rolling speeds and water flows

IV. GENERAL EVALUATION

With this study, as a result of annealing at different annealing temperatures, the hot rolling exit speed and accordingly the tempcore water cooling flow rate were adjusted, and similar drawing properties were obtained in different group processes. In this way, tempcore operations in accordance with the standards have been achieved.

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