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Professional paper

THE INFLUENCE OF MANGANESE ON THE TENSILE STRENGTH OF HIGH CARBON STEEL C66D

Aida Imamović[1], Omer Kablar[2], Mirsada Oruč[1], Vedina Purić-Selimović[2], Lamija Sušić[1]

[1] University of Zenica, Faculty of Engineering and Natural Science, [2] ArcelorMittal d.o.o. Zenica;

ABSTRACT

Modern steel production cannot be imagined without manganese, because almost all steels contain manganese.

In this paper, we present the impact of manganese on the tensile strength values of high-carbon steel. This paper presents an improvement in the quality of wire rolling with control of manganese content in steel and the value of C-equivalent, in industrial conditions, which is of particular importance in the production of this quality of steel.

For the presented quality of rolled wire made of high-carbon steel, it is possible to control the C-equivalent in high-carbon steel to achieve values for tensile strength in exceptionally narrow tolerances of 1000 ± 30 MPa.

Keywords: high carbon steel, manganese influence, tensile strength, C-equivalent

Corresponding Author:
Aida Imamović
Affiliation:
University of Zenica, Faculty of Engineering and Natural Science
Travnička cesta 1, Zenica 72 000, Bosnia and Herzegovina
Tel.: +387 32 401 831; fax: +387 32 406 903
E-mail address: aida.imamovic@unze.ba

1. INTRODUCTION

Carbon steel or non-alloy steel is of ordinary quality and is classified mainly according to mechanical properties. It is used for lightly loaded parts of machines, devices, vehicles, or for bars and grates. Unalloyed or carbon steels, which, depending on the proportion of harmful phosphorus and sulfur impurities (i.e. purity), can be of ordinary quality with a maximum of 0.050% P and S individually, high-quality with a maximum of 0.045% P and S individually, and noble with a maximum up to 0.035% P and S individually. Carbon steels usually have a content of 0.05 to 1.35% C. To the carbon content, structural steels are further divided into low carbon (up to 0.20 %C), medium carbon (0.20 to 0.50 %C), and high carbon (more than 0.50 %C) [1].

Carbon steels are mainly divided into low-carbon, medium-carbon, and high-carbon steels according to EN 10020 [1]:

- ***Low-carbon steels*** have mainly ferritic microstructure, and their properties are close to pure iron, which is reflected in the possibilities of their welding. Their main disadvantage is the inability to achieve high hardness by hardening. Low-carbon steels have a carbon content of 0.05% to 0.20%.
- ***Medium carbon steels*** have a mixed, pearlitic-ferritic structure. In contrast to low-carbon steels, they have higher strength and hardness, as well as lower toughness and elongation. Medium carbon steels (0.20% - 0.50% of carbon) are used mainly in the normalized state.

- ***High-carbon steels*** have a perlite-cementite structure, which is the main cause of increased hardness and reduced toughness and elongation. They are widely used in the manufacture of tools, because of excellent hardenability, but reduced elongation. High-carbon steels have a carbon content above 0.5%. It has the highest hardness and toughness of carbon steels and the lowest ductility.

2. INFLUENCE OF MANGANESE ON STEEL QUALITY

Modern steel production can not be imagined without manganese, because almost all steels contain manganese. In steel production, manganese is added as a ferroalloy to molten steel, thus achieving several beneficial effects. Manganese acts as a deoxidizer and desulfurizer and binds oxygen and sulphur. In addition, the presence of manganese in steel greatly increases the hardness of steel and wear resistance. Due to this, almost all steels contain manganese within certain limits, most often from 0.3% to 1.5%.

Figure 1 shows the positive effect of manganese and carbon content on the tensile strength of hot-rolled steels. Increasing the manganese content increases the tensile strength of rolled products and is especially effective when the upper limit of manganese is allowed. By reducing the manganese content below 1%, the tensile strength decreases significantly, as shown in Figure 1 [2,3].

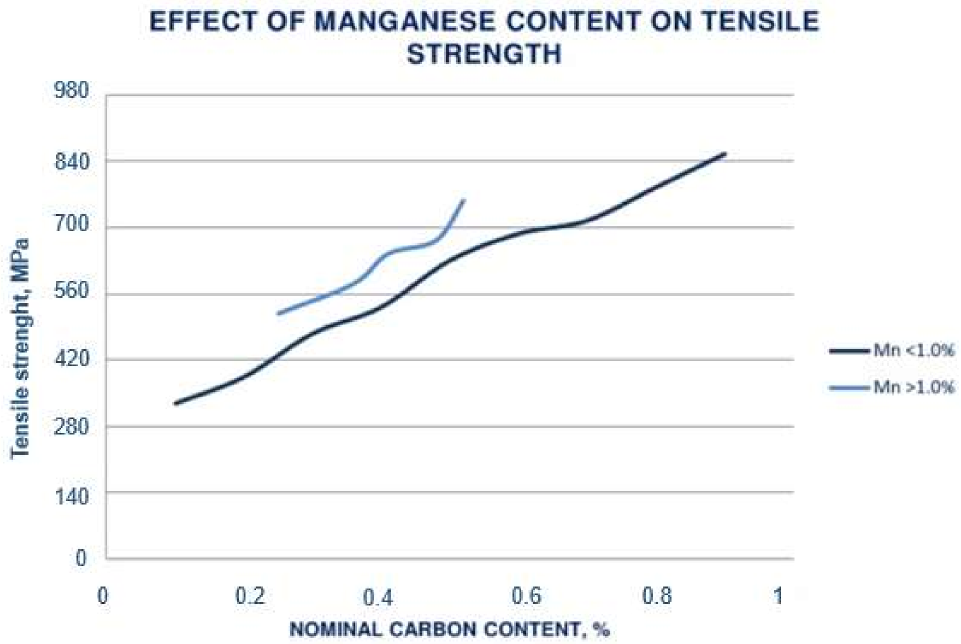

Figure 1. Influence of manganese on tensile strength [3]

The effect of manganese on improving the mechanical properties of steel also depends on the carbon content. Manganese also reduces the critical cooling rate during solidification by shifting the austenite conversion temperature to lower temperatures, thus increasing the hardness of the steel. Manganese also reduces the critical cooling rate during solidification by shifting the austenite transformation temperature to lower temperatures. Its effect on hardness is greater than other alloying elements. Manganese, as a gamma element, expands the austenitic area but also stimulates the formation of coarse grains and the appearance of brittleness.

Both carbon and manganese have been found to have a significant effect on tensile strength. Carbon equivalent (C_{eq}) is an important tool for determining different properties (prediction of hardness, weldability, and microstructure) of an alloy when more elements than carbon are used as an alloying element. C_{eq} calculation is used in welding, heat treatment, and casting processes. Carbon equivalent (C_{eq}) is used in welding to define the weldability of steel and to know how different alloying elements affect the hardness and microstructure of the material to be welded. As C_{eq} values increase, the weldability of the material decreases. Low carbon equivalent materials offer excellent weldability with minimal precautions [3, 4].

For special shipbuilding and other high-strength steels with a carbon content over 0.18%, C_{eq} can be calculated:

$$C_{eq} = \%C + \frac{(\%Mn + \%Si)}{6} + \frac{(\%Cr + \%Mo + \%V)}{5} + \frac{(\%Cu + \%Ni)}{15} \quad (1)$$

Depending on the amount of carbon equivalent (C_{eq}) obtained, weldability is estimated [5]:

$C_{eq} < 0.25 \rightarrow$ good weldability
$0.25 < C_{eq} \leq 0.35 \rightarrow$ satisfactory weldability
$0.35 < C_{eq} \leq 0.45 \rightarrow$ limited weldability
$C_{eq} > 0.45 \rightarrow$ very poor weldability

3. PRACTICAL WORK

Steel marked C66D is a high-carbon steel with chemical composition according to standard EN ISO 16120 which is used for various purposes and most often for the production of wire intended for drawing. The main characteristic in the industrial production of this steel is the achievement of the requested value of tensile strength. The values of tensile strength were determined in the ArcelorMittal Zenica laboratories according to the BAS EN ISO 6892-1:2017 standard and according to the customer's request.

Table 1. Characteristics of C66D steel according to standard EN ISO 16120 [2]

Element	C	Mn	Si	P	S	Tensile strength R_m (N/mm^2)
mass. [%]	0.63-0.68	0.60-0.90	0.10-0.30	≤ 0.030	≤ 0.030	1000

This type of steel, with manganese in the range of 0.60-0.90, is used for the production of 5.5 mm wire in a coil for the following use: production of reinforcing mesh, cold drawing, ribbing of wire, springs other steel products for general use.

Continuously cast billets with dimensions of 120x120x12000 mm were used for the production of rolled wire with a diameter of ϕ5.5 mm from steel C66D, the chemical composition of which corresponds to the specified steel according to the EN standard.

Billets are first heated in a walking hearth furnace to rolling temperature 1160°C. The total number of rolling mill stands that rolling piece passed to reach desire diameter 5.5 mm is 25th. To reach mechanical properties according to standard the very important procedure is the thermical treatment STELMOR process.

Thermal treatment performed using the STELMOR process includes:

- Water cooling with two water boxes by adjustment of the valves which supply water to the eater cooling zones. Different adjustment may be required to obtain the same laying temperatures for different wire dimensions. After water cooling, the temperature of the wire for grade C66D is 830 ± 10 °C;
- Cooling with four air fans and with speed adjustment of stelmor conveyor. The conveyor speed is selected to provide appropriate spacing between wire rings on conveyor. And air nozzles are design to supply more cooling at the side of conveyor than at the center in purpose uniformity of properties at all position on the conveyor.

STELMOR process has the role of responding to the requirements of microstructure and mechanical properties by controlled cooling. After cooling with water in two water boxes, the wire is further transport to the STELMOR conveyor where the second phase of cooling begins and that cooling via air fans. After that, coils of wire are formed and thus the cooling process is completed [6]. Cooling conditions on the conveyor must be set so as to achieve the highest possible cooling speed, which is achieved by establishing the so-called "open ring in the ring" in combination with a sufficient number of high capacity cooling fans, Figure 2.

Figure 2. Air Cooling process at STELMOR

The goal of the STELMOR process is to achieve the highest possible cooling rate, as well as to control the rate of transformation of austenite into ferrite-perlite because by increasing the cooling rate, smaller ferrite grains are obtained and pearlite lamellas become thinner. In that way, a higher degree of cold plastic deformation is enabled until the appearance of fracture.

Because C and Mn contents have a significant effect on tensile strength, therefore, care must be taken about the carbon equivalent C_{eq}. In this case, for C66D steel, C_{eq} was calculated using the following equation [5]:

$$C_{eq} = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Cu + \%Ni}{15} \tag{2}$$

In the practical part, 6 samples of C66D steel billets were analyzed, in which the Mn content and the calculated C_{eq} based on the previous equation and are presented in Table 2 [7]:

The value of C-equivalent increases with a higher manganese content and should take into account the mechanical properties of steel, Figure 3.

Table 2. Mn, C_{eq}, and tensile strength of produced C66D steel billets

Sample	1	2	3	4	5	6
Mn	0.66	0.67	0.68	0.68	0.69	0.71
C_{eq}	0.769	0.774	0.791	0.787	0.781	0.820
R_m, MPa	959	969	1050	1009	1005	1059

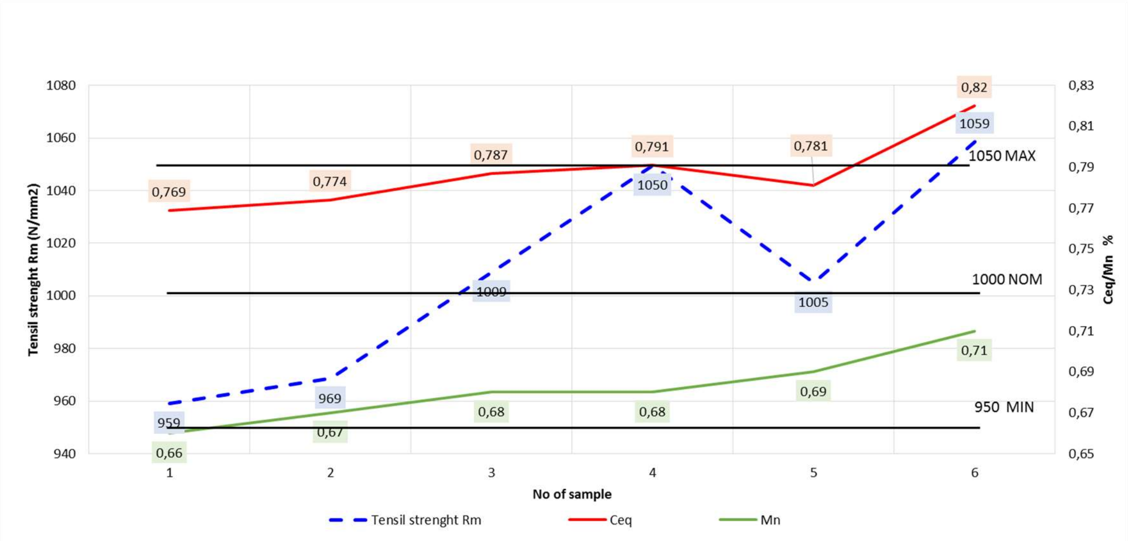

Figure 3. Mn content, C_{eq} value, and tensile strength values of C66D steel

It can be seen from Figure 3 that with a C_{eq} greater than 0.78, tensile strength values of at least 1000 MPa can be achieved with certainty. This value corresponds to a percentage of manganese of 0.68% and carbon equivalent C_{eq} of 0.787. It can be concluded that Mn as an element has a positive effect on tensile strength, which could be seen in melt No. 3 where the tensile strength had the highest value to other melts 1059 MPa, and where the Mn content was also the highest.
By controlling the manganese content, with the same production conditions, i.e. rolling, it is possible to control the tensile strength values of the rolled wire.
For the presented quality of rolled wire made of high carbon steel, it is possible with the current improved technology in ArcelorMittal Zenica with control of C_{eq} value to achieve values for tensile strength (R_m) in tolerance of 1000 ± 30 MPa.

4. CONCLUSION

- With the same parameters of the Stelmor process, the tensile strength for different values of Mn and thus C_{eq} was different.
- Based on the conducted research, it can be concluded that Mn as an element has a positive effect on tensile strength [8].
- In order to achieve higher tensile strength, it is best to limit the Mn content from 0.68% to 0.69%.
- Carbon increases tensile strength as well as manganese. These elements directly affect the value of C_{eq}.
- It can be concluded that the C_{eq} should be kept in the range from 0.78 % to 0.82%.
- Improving the rolling quality of C66D steel wire and controlled values for C_{eq} has contributed to the fact that values for tensile strength can be achieved in a tolerance of 1000 ± 30 MPa.

Conflict of interest
The authors declare no conflict of interest.

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