

# Studies of the Properties and Microstructure of Heat Treated 0.27% C and 0.84% Mn Steel

Masoud Ibrahim Mohamed

Chemical and Materials Engineering Department  
Northern Border University, Arar, Saudi Arabia  
On leave from Mechanical Engineering Department,  
Faculty of Engineering, Fayoum University, Egypt  
ibrahim\_64@yahoo.com

**Abstract**—In the present work, different heat treatments like hardening with different cooling rates followed by tempering at different temperatures have been performed. The material used in this study is carbon steel of 0.27% C and 0.84% Mn. Samples of as-rolled steel were subjected to different heat treatment processes. The steel was heated to the austenitizing temperature of 870°C for 2hrs followed by water quenching, oil quenching, air and furnace cooling. Water and oil quenched samples were subjected to tempering for one hour at temperatures of 250°C, 350°C, 450°C and 550°C. Tensile and impact tests were carried out for as rolled and heat-treated steel. Results show that the heat treated steel revealed an excellent combination of tensile strength and impact strength, which is suitable for structural applications. Optical metallographic investigation was carried out for all samples compared with the as rolled steel. The heat treatment revealed remarkable changes in steel morphology and mechanical properties.

**Keywords**—medium carbon steel; heat treatment; mechanical properties; optical micrograph; tempering

## I. INTRODUCTION

Steel with low carbon content has nearly the same properties as iron, it is soft and easy to deform, and it has low tensile strength and hardness. As the carbon content increases, the steel becomes harder and stronger but less ductile and more difficult to weld [1-3]. Carbon steel with 0.27% C and 0.84% Mn is broadly used in the production of machinery parts like shafts and gears, and as structure steel in many industrial applications [4-7]. The need to produce higher strength steels, stronger than those obtained in conventional controlled rolled high strength micro-alloyed grade has led to the improvement of microstructural strengthened steels through different heat treatment. Heat treatment involves the application of heat to a material in order to bring changes in the microstructure and modify the material properties. During the heat treatment process, the material usually shows phase microstructural and crystallographic changes [8-11]. The purpose of heat treating carbon steel is to change the mechanical properties of steel, usually ductility, hardness, yield strength tensile strength and impact resistance. The impact strength of the heat-treated specimens are higher than that of the as rolled, because of the

martensite formed during the heat treatment processes [9-11].

## II. EXPERIMENTAL METHOD

The chemical composition of medium carbon steel (ASTM A-36) used for this investigation is given in Table I.

TABLE I. STEEL CHEMICAL COMPOSITION, WT. %.

C	Mn	Si	Cu	P	S	Zn
0.27	0.84	0.24	0.095	0.02	0.02	0.05

Samples for mechanical tests and microscopic scanning were cut out from the as rolled (AR) steel. The samples for tensile test were prepared according to ASTM E8. The impact test sample was cut with dimensions of 55mmx10mmx10mm that follow standard dimensions for Charpy impact test ASTM E23. The samples for the mechanical tests and microstructure investigations would be heat-treated (HT) to 870°C followed by, furnace cooling (FC), air-cooling (AC), water quenching (WQ) and oil quenching (OQ). Water quenched samples were tempered at temperatures of 250°C (WQT1), 350°C (WQT2), 450°C (WQT3) and 550°C (WQT4). Oil quenched samples were tempered at the same temperatures (OQT1-OQT4). Tensile and impact tests were carried out for AR and HT samples. All samples (AR and HT) would undergo microstructure analysis using metallurgical microscope. The results of the mechanical tests and optical micrograph were analyzed.

## III. RESULTS AND DISCUSSION

### A. Tensile Test

Tensile tests were carried out for AR and HT steels. Figure 1 shows the effect of quenching media of the stress strain curve for steel ASTM A-36. Maximum stress increased by the effect of hardening (WQ, OQ) with a decrease of elongation. Figures 2 and 3 show the effect of tempering temperatures on WQ and OQ steels respectively. WQ steels show a slight decrease in UTS with higher increase in elongation tempering at T1 and T2 while all tempering temperatures remarkably decrease UTS of th OQ steels, with T1 and T3 revealing higher ductility. Figure

4 is a summary for the effect of tempering temperature on the ultimate tensile stress (UTS) and yield stress ( $\sigma_y$ ) of the WQ and OQ steel. It is clear that, the UTS increased after WQ and OQ compared with AR steel. After tempering, UTS decreased while maximum elongation increased.

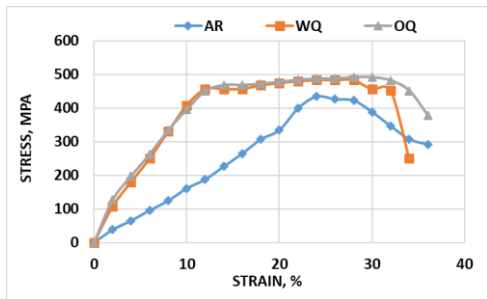


Fig. 1. Effect of quenching media from 870°C into water and oil quenching

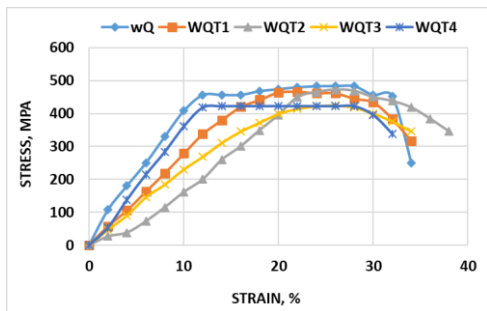


Fig. 2. Effect of water quenching at 870°C followed by tempering at T1, T2, T3 and T4

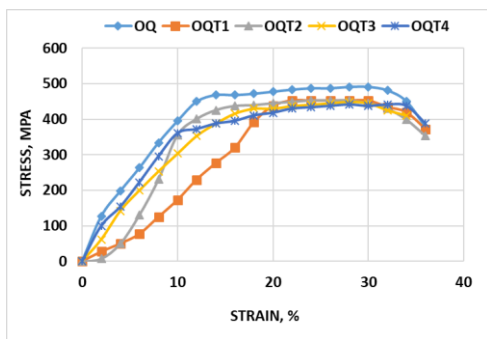


Fig. 3. Effect of oil quenching at 870°C followed by tempering at T1, T2, T3 and T4

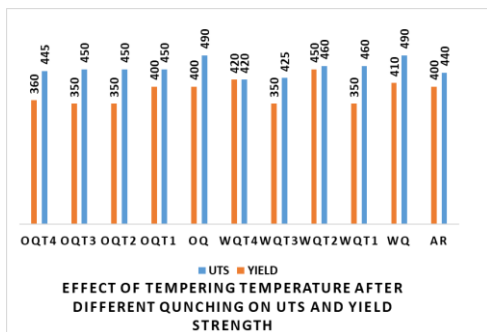


Fig. 4. Effect of tempering temperature after different quenching on UTS and yield stress.

B. Optical Micrograph

The effect of quenching media on the microstructure of ASTM A -36 steel is shown in Figure 5. The AR steel reveals ferrite and perlite phases while, fine needle like martensite were obtained from WQ steel. Oil quenched steel shows retained austenite with some martensite. This change in the microstructure due to hardening can explain the increase in maximum strength obtained in Figure 1. The effect of tempering temperature on WQ and OQ steels is shown in Figures 6 and 7 respectively. Figure 6 shows the effect of tempering temperature on the WQ steel. Water quenched steel revealed the formation of lath martensite. Tempered martensite is shown for the tempered WQ and OQ steel.

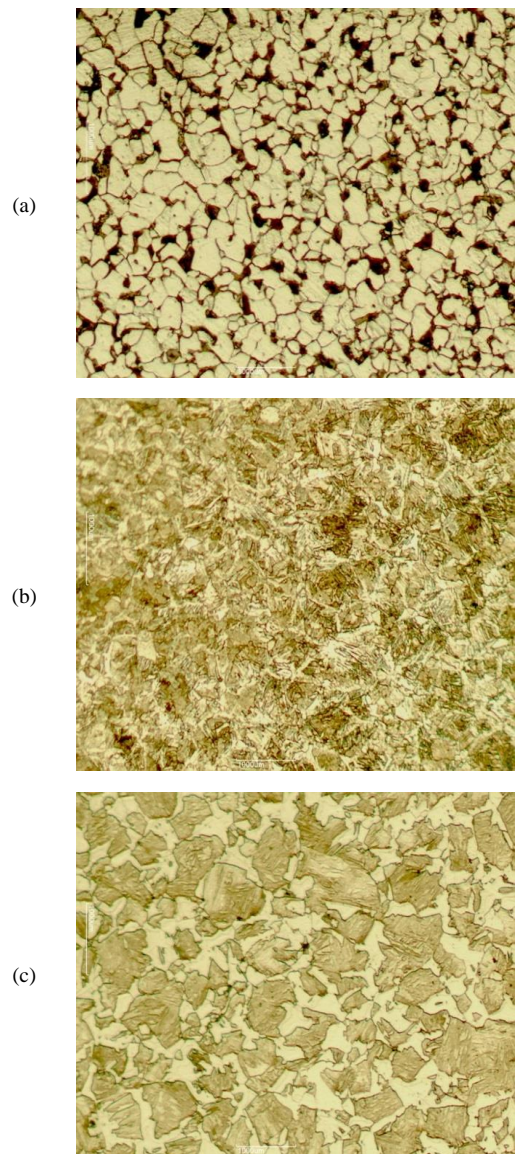


Fig. 5. Optical micrograph of (a) AR, (b) WQ and (c) OQ steel.

C. Impact Tests

The effects of heat treatment on the absorbed energy of medium carbon steel are shown in Figure 8. The absorbed



energy increased by tempering of WQ steel at temperature of 450°C.

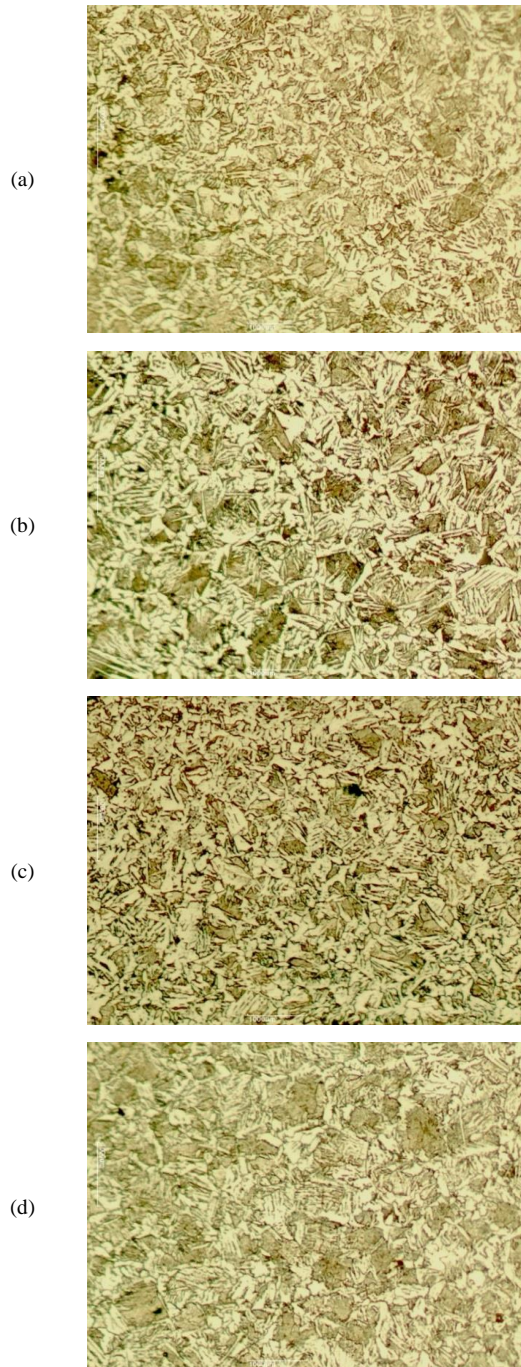


Fig. 6. Optical micrograph of WQ and tempered steel at (a) 250°C, (b) 350°C, (c) 450°C and (d) 550°C.

#### IV. CONCLUSIONS

Microscopic investigations, tensile and impact tests were carried out for ASTM A-36 steel of 0.27% C. The results of the experimental work can be summarized as:

- WQ and OQ steels revealed higher tensile strength due to

the effect of martensite formation.

- UTS, Yield strength and % elongation of WQ steel seems to be higher than that of OQ steel after tempering at 350°C.
- Tempering after quenching revealed remarkable improvement especially at temperature of 350°C.
- Impact energy for WQ steel is higher than for OQ steel, impact energy increased to maximum at tempering temperature of 450°C for WQ steel.

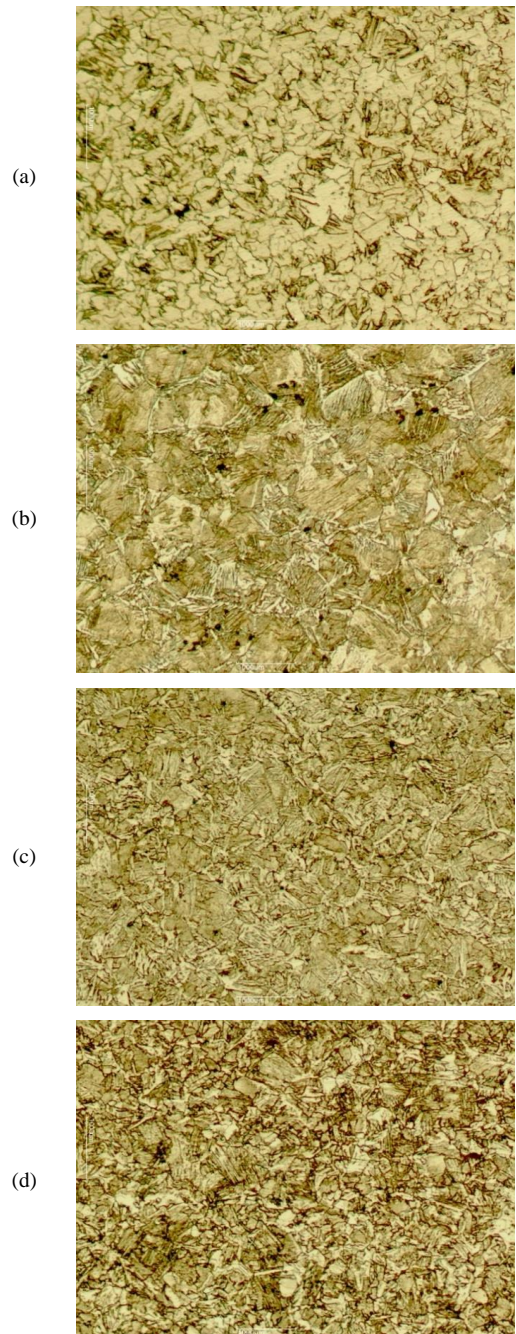


Fig. 7. Optical micrograph of OQ and tempered steel at (a) 250°C, (b) 350°C, (c) 450°C and (d) 550°C.

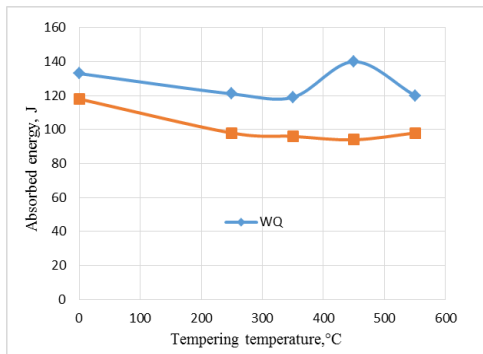


Fig. 8. Effect of tempering temperatures on the absorbed energy of WQ and OQ steel

#### NOMENCLATURE

AR	As Rolled
WQ	Water Quenched
OQ	Oil Quenched
WQT1	Water Quenched + Tempering at 250°C
WQT2	Water Quenched+ Tempering at 350°C
WQT3	Water Quenched+ Tempering at 450°C
WQT4	Water Quenched+ Tempering at 550°C
OQT1	Oil Quenched+ Tempering at 250°C
OQT2	Oil Quenched+ Tempering at 350°C
OQT3	Oil Quenched+ Tempering at 450°C
OQT4	Oil Quenched+ Tempering at 550°C
OM	Optical Micrograph
Hv	Hardness Vickers
UTS	Ultimate Tensile Strength
$\sigma_y$	Yield stress

#### ACKNOWLEDGEMENT

Author wishes to acknowledge the approval and the support of this research study by the grant no. (7390-ENG-2017-1-8-F) from the Deanship of Scientific Research in Northern Border University, Arar, KSA.

#### REFERENCES

- [1] D. O. Oluayemi, O. I. Oluwole, B. O. Adewuyib, "Studies of the Properties of Heat Treated Rolled Medium Carbon Steel", *Materials Research*, Vol. 14, No. 2, pp. 135-141, 2011
- [2] O. O. Daramola, B. O. Adewuyi, I. O. Oladele, "Effects of Heat Treatment on the Mechanical Properties of Rolled Medium Carbon Steel", *Journal of Minerals & Materials Characterization & Engineering*, Vol. 9, No. 8, pp.693-708, 2010
- [3] B. S. Motagi, R. Bhosle, "Effect of Heat Treatment on Microstructure and Mechanical Properties of Medium Carbon Steel", *International Journal of Engineering Research and Development*, Vol. 2, No. 1, pp. 7-13, 2012
- [4] N. M. Ismail, N. A. A. Khatif, M. A. Kamil, A. Kecik, M. A. H. Shaharudi, "The effect of heat treatment on the hardness and impact properties of medium carbon steel", *IOP Conf. Series: Materials Science and Engineering*, Vol. 114, No. 1, pp. 012108-012106, IOP Publishing, 2016
- [5] D. A. Fadare, T. G. Fadara, O. Y. Akanbi, "Effect of Heat Treatment on Mechanical Properties and Microstructure of NST 37-2 Steel", *Journal of Minerals & Materials Characterization & Engineering*, Vol. 10, No. 3, pp. 299-308, 2011
- [6] O. O. Joseph, O. O. Joseph, R. O. Leramo1, O. S. Ojudun, "Effect of Heat Treatment on Microstructure and Mechanical Properties of SAE 1025 Steel: Analysis by one-way ANOVA", *Journal of Materials and Environmental Science*, Vol. 6, No. 1, pp. 101-106, 2015
- [7] J. K. Odusote, T. K. Ajiboye, A. B. Rabi, "Evaluation of Mechanical Properties of Medium Carbon Steel Quenched in Water and Oil", *AU Journal of Technology*, Vol. 15, No. 4, pp. 218-224, 2012
- [8] V. K. Murugan, P. K. Mathews, "Effect of Tempering Behavior on Heat Treated Medium Carbon (C 35 Mn 75) Steel", *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 2, No. 4, pp. 945-9540, 2013
- [9] S. A. Tukur, M. M. Usman, I. Muhammad, N. A. Sulaiman, "Effect of Tempering Temperature on Mechanical Properties of Medium Carbon Steel", *International Journal of Engineering Trends and Technology*, Vol. 9 No. 15, pp. 798-800, 2014
- [10] A. K. Tanwer, "Effect of Various Heat Treatment Processes on Mechanical Properties of Mild Steel and Stainless Steel", *American International Journal of Research in Science, Technology, Engineering & Mathematics*, Vol. 8, No. 1, pp. 57-61, 2014
- [11] A. Calik, "Effect of cooling rate on hardness and microstructure of AISI 1020, AISI 1040 and AISI 1060 Steels", *International Journal of Physical Sciences*, Vol. 4, No. 9, pp. 514-518, 2009