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Effect of Tempering Temperature on the Mechanical Properties and Microstructure of low alloy Steel DIN 41Cr4

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Abstract

This study focuses on the impact of tempering temperature on the microstructure and mechanical characteristics of low alloy steel DIN 41Cr4, which is utilised by an Algerian manufacturing company to produce bolts, threaded rod, screws, and shafts. By performing heat treatment at temperatures for quenching and tempering, we use an experimental approach. All of the heat-treated samples underwent mechanical testing for tensile, impact fracture toughness, hardness tests, and microstructures. To examine the impact of microstructure, all samples were austenitized at 850 °C for 30 min, followed by oil quenching, tempering at 200 °C to 600 °C for 1 h, and air cooling. According to the results of tensile testing, when tempering temperature rises, yield strength (YS), ultimate tensile strength (UTS), and hardness all drop.

Keywords: tempering temperature; mechanical property; microstructure; low alloy steel;

1. Introduction

Numerous industries, especially the automobile industry, have increased their use of low alloy steel DIN 41Cr4 [1–7]. To enhance the mechanical qualities and lengthen the service life, this class of steel has been quenched and tempered [8–10]. Industrial demands for greater mechanical qualities and longer service lives for these steels necessitate compositional changes and different heat treatment processes by the inclusion of Cr, Ni, and Mn components [11–16].

Many scientists [17–20] have worked hard to understand how quenching and tempering temperatures (Q & T) affect mechanical characteristics and microstructure. When S.Z. Qamar investigated how heat treatment affected the mechanical properties of H11 tool steel, he discovered that yield strength initially decreased, then increased, and then increased again. Hardness increased to a maximum and then gradually decreased with increasing temper temperatures. After researching the impact of tempering temperature on the mechanical characteristics of cast L35HM steel, R. Zapala and B. Kalandyk found that the values of elongation (EL) and retained austenite (RA) did not differ significantly. Large variations in strength and hardness between the tempered metals have attracted attention.

In the present work the mechanical properties and microstructure of quenched and tempered steel DIN 41Cr4vary by tempering at 200, 600 °C for all samples at different temperatures were studied.

2. EXPERIMENTAL

The chemical composition of the test material DIN 41 Cr4 (AFNOR 42C4) was determined by emission spectrometry in industrial company BCR, Relizane (Algeria)Figure1.The chemical composition of investigated steel is shown in Table1.In the present work, all the samples of tensile testing and impact test were austenitized at 850°C for 30 min, followed by oil quenching, and then tempered at different temperatures that range from 200 to 600°C (Figure 2), for each step the tempering duration is 1hour and cooled in air, schematic of heat treatment cycle used in this study is shown in Figure 2.

After heat treatment, the specimens were tested by tensile test, impact toughness test (Kv) and completed with Rockwell hardness measurements, for the tensile testing and impact toughness the specimens with the dimensions are shown in Figure3 and Figure 4.For the tensile testing, we used the KARL FRANK GMBH, WEINHEIM-BIRKENAU, type 83431 Werk–Nr 10650 machine Metallographic examinations of samples were observed by a light microscope, they were mechanically polished and etched with 3% nital solution, test specimen polishing shown in Figure 5. The average value of three specimens were considered and the deviation of HRC is 0.02. (2%).

Figure 1. Emission spectrometry

Table 1. Chemical compositions of DIN 41Cr4 steel (mass fraction, %)

C	Mn	Si	Al	Cr	Mo	Cu	P	S	Ni
0,43	0,74	0,25	0,03	1,05	0,04	0,12	0,013	0,012	0,17

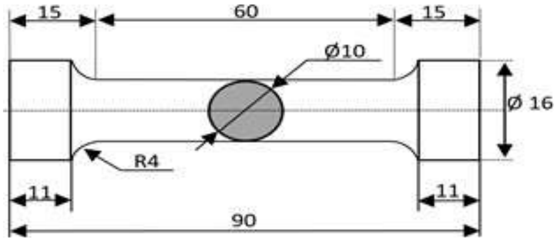

Figure 3. Schematic diagram of tensile testing sample

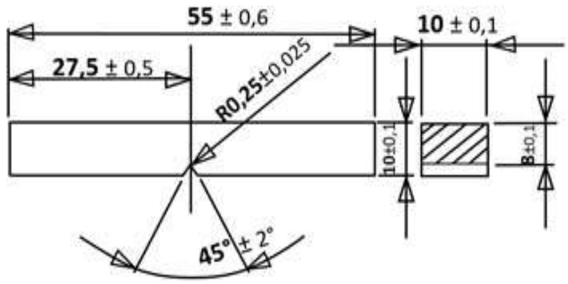

Figure4. Schematic diagram of impact test sample

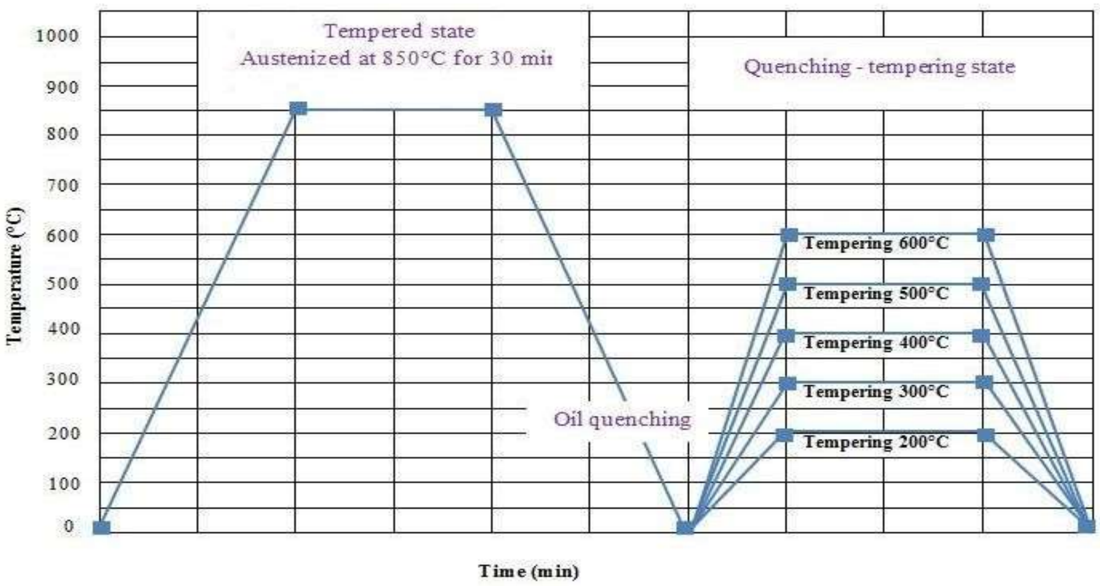

Figure 2. Schematic illustration of heat treatment cycle used in this study

Figure 5. Test specimen polishing on disc abrasive

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3. RESULTS AND DISCUSSIONS

Fracture toughness, $/MPam^{1/2}$ can be estimated from the mechanical properties obtained by tensile test. The Rolfe-Novak correlation can be successfully used for that purpose [15]. In table 2, we present a short summary of the results of mechanical tests carried out on the DIN41Cr4 steel.

$K_{IC} = \sqrt{6.4\ (100\mathrm{KV} - R_e)}$ (1)Where:
: Fracture toughness
R_e: Yield strength
KV: Impact energy

Hardness

Figure6 exhibits the influence of tempering temperature at various tempering temperatures for 1hour on the average value of Rockwell hardness. It can be seen that the hardness of 41Cr4 steel gradually decreases from 48 HRC to 24 HRC with increasing the tempering temperatures in the range of 200 - 600°C; it is found that the rate of decrease of Rockwell hardness in lower tempering temperature range of 200-400 °C is higher than that in temperatures ranges of 400-500 °C and 500- 600°C. It was observed that different heat treatment processes gave different hardness. The hardness gradually decreases in ranges of 200 -400 °C and 500- 600°C but from 400 to 500°C the hardness decrease sharply about 10 HRC. It can be explained on the phase transformation of steel during the quenching process, the tempered martensite formation, the reduction in dislocation density and coarsening of transition carbides [4, 7, 16, 20].

Many researches [16-18] have done the effect of retained austenite and the reduction in dislocation density and coarsening of transition carbides for decreasing of hardness, this material has a martensitic structure combined of bainite, and it was brittle after the quenching state [19,20]. The carbon rejected for these two phases is the major factor controlling all the microstructural transformation of the steel studied, the addition elements such as Cr and Mn are also known to promote steel during continuous cooling by bainite formation, with the increase of Mn and Cr content, the bainitic ferrite plate thickness decreased and the volume fraction of retained austenite increased. The bainite can also be produced as a result of decomposition of austenite γ during quenching, a small change in hardness at low tempering temperatures between 200 - 300°C is observed [21,22]. It can be explained that the decrease in hardness could be attributed to softening effect of the hard martensite and recrystallization of more ferrite on tempering [12].

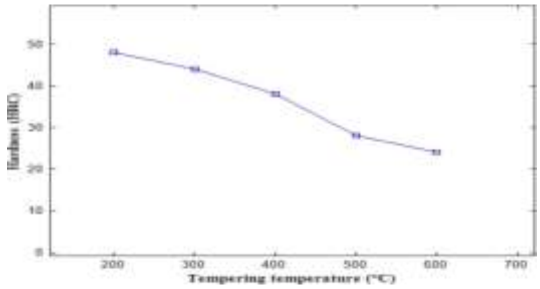

Figure 6. Variation of hardness with tempering temperature

Tensile properties

The values of tensile properties of DIN 41Cr4 steel are shown in Figure 7. There are three stages of yield strength (YS) and the ultimate tensile strength (UTS) as a function of the tempering temperature.

1. With the tempering temperature increasing up to 400°C, the YS and UTS slightly decreases about 100 MPa.
2. From 400 to 500°C, the YS and UTS decrease sharply from 1377 to 970.6MPa for YS and 1509 to 1061MPa for UTS.
3. From 500 to 600°C the YS and UTS decrease gradually about 200 MPa.

Many research studies [23-25] explained that with an increase in the tempering temperature, the carbon concentration of the matrix in the tempered martensite decreases due to the diffusion of carbon atoms into cementite. Therefore, the strength of the tempered martensite decreases, and its ductility increases. As a result, the higher the tempering temperature, the lower the dislocation density, and the lower the rate of work hardening [26-28].

It can be seen also from Figure7 that there is no significant effect of phenomenon of tempered martensite embrittlement (TME) on the tensile properties [29, 30].

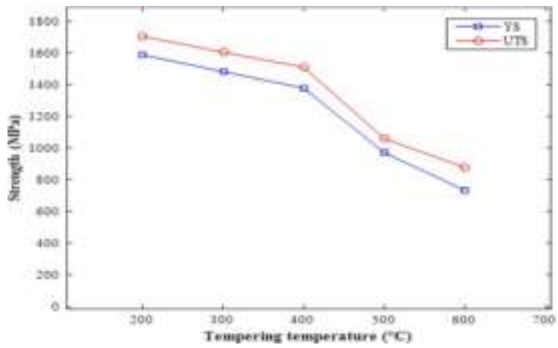

Figure 7. Variations of tensile properties with tempering temperature

Table 2: Mechanical test results for heat treatment

Treatment	YS [MPa]	UTS [MPa]	EL [%]	Kv [J]	$K_{IC}[MPa\sqrt{m}]$	HRC
quenching 850°C.tempering 200°C	1586.11	1703.08	2.35	9.51	5.52	48.07
quenching 850°C.tempering 300°C	1480.10	1603.13	3.67	10.33	6.07	44.12
quenching 850°C.tempering 400°C	1377.02	1509.10	4.04	17.02	10.39	38.17
quenching 850°C.tempering 500°C	970.16	1061.03	8.05	99.33	63.24	28.03
quenching 850°C.tempering 600°C	773.18	880.05	9.66	118.66	75.69	24.15

Impact energy

The impact energy is shown in Figure 8, the variation of impact energy KV depending on the tempering temperature. The variation of impact energy with temperature consist a several stages. A Charpy hammer with an energy of 150J according to ASTM D6110 [38].

1. With the tempering temperature increasing up to 300°C, the impact energy increases slowly;
2. From 300 to 400°C, the impact of energy increases slightly about 7 J;
3. From 400 to 500°C, the impact of energy increases very sharply from 17 to 99.33 J;
4. From 500 to 600°C, the impact of energy increases sharply about 20J.

At state of tempering temperature 200- 400°C the impact energy is low (9,5J - 17) , it causes a slight increase in this energy at the tempering temperature 400°C, above the temperature 400°C, impact toughness of DIN 41Cr4 is increased when the tempering temperature is increased. Same researches [4, 31] explained that retained austenite has soft structure and increment of impact toughness directly related to retained austenite. Developments of tempering processes and coarsening of the structure are responsible for this increase of impact toughness; this behavior reflects a growing plasticity of steel studied as the tempering temperature increases. It can be observed phenomenon of ductile-brittle transition temperature according the impact energy [32].

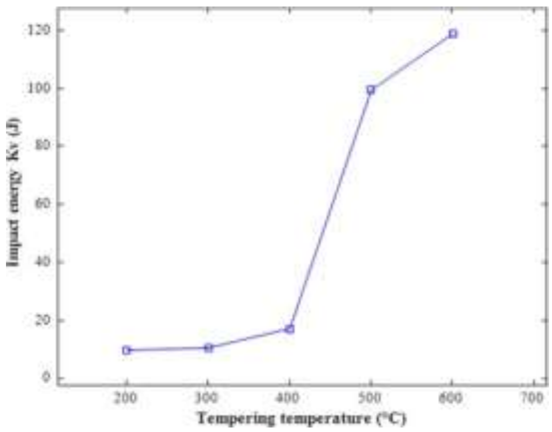

Figure 8. Variations of impact energy with tempering temperature

Elongation

The variation of elongation (EL) as function as tempering temperature is shown in Figure9.It can be seen the increase of elongation with the tempering temperature increasing up to 600°C, the gradual increasing of percent elongation due to the effect of retained austenite and the decrease of dislocation density and lower work hardening rate at high tempering temperature [8, 33].

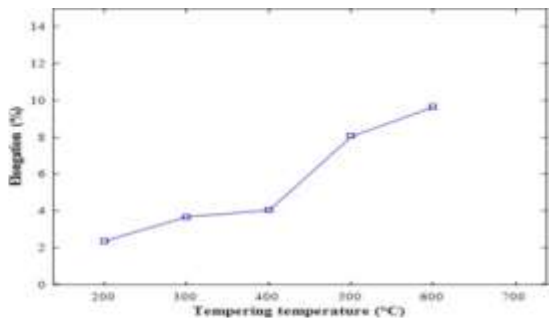

Figure 9. Variations of elongation with tempering temperature

Grain size

The Figure 10 shows the evolution of grain size according to the tempering temperature, at range of tempering temperatures of 200-500°C the grain size is gradually increase, above tempering temperature 500°C the grain size will be increased sharply until the value of 14 µm which corresponds to the tempering temperature of 600°C.

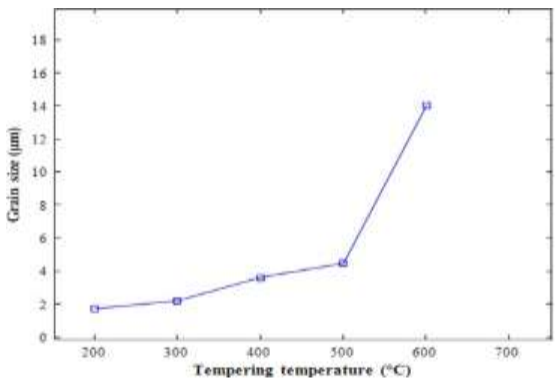

Figure 10. Variations of grain size with tempering temperature

Morphology and microstructure

The microstructural analysis of samples is shown in Figure 11, in (Figure 11 (a)) the microstructure consists of tempered martensite (M) and characterized by cementite plates in the ferrite matrix at the tempered microstructure state [7, 34]. The microstructure of the sample tempered at 200°C (Figure 11 (b)) consists of the lath martensite, which differs slightly from the quenched sample [33-38], the carbide precipitation takes place of the lath martensite with increasing of tempering temperature. When the tempering temperature increases to 400 °C (Figure 11 (c)),the microstructure of the tempered sample mainly consist the lath martensite and ferrite , some research [4,7] explained that the austenite decomposes and further increase of temperature ranges (300 - 450°C) leads to the formation of cementite (Fe3C) platelet phase (Figure 11(c)).The microstructure of the tempered sample correspond to the tempering temperature 600 °C (Figure 11 (d)), consists of ferrite and carbides.

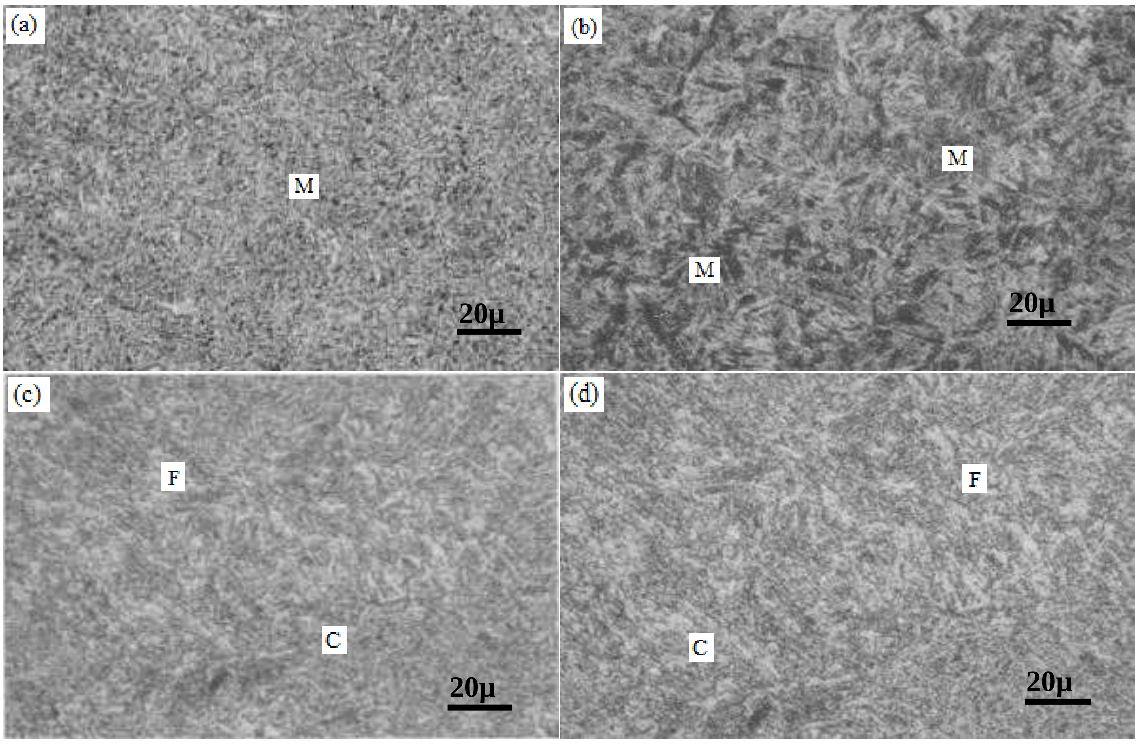

Figure 11. Optical micrographs of investigated DIN 41Cr4 steel as function of heat treatment

(a) As-quenched sample; (b) Tempering at 200 °C; (b) Tempering at 400 °C, (d) Tempering at 600 °C

4. CONCLUSION

Testing of all samples (tensile testing and impact test) with heat treatment of tempering temperature revealed the effect of tempering temperature on the mechanical properties of DIN 41Cr4 steel.

The following is a summary of the main conclusions:

- Hardness declines steadily until tempering temperature reaches 400°C, at which point it declines relatively abruptly;
- Impact toughness steadily rises until tempering temperature becomes 400°C, then it rises sharply;
- Percent elongation steadily rises until tempering temperature becomes 400°C, then it rises rather sharply;
- At tempering temperature of 200°C, the microstructure of DIN 41Cr4 steel consists of lath martensite, with incised grain boundaries.

REFERENCES

[1] Rajan KM. Effect of heat treatment of perform on the mechanical properties of flow formed AISI 4130 steel tubes. J Mater Process Technol (2002); 125:503-11.

[2] J. Maciejewski. C. Regulski. Fractureassessment of martempered and quenched and tempered alloy steel, J Fail. Anal, and Preven. (2009) 9:397– 408.

[3] A.H. Meysami, R. Ghasemzadeh, S.H. Seyedein, M.R. Aboutalebi. An investigation on the microstructure and mechanical properties of direct-quenched and tempered AISI 4140 steel.31 (2010) 1570 -1575.

[4] LI Hong-ying , HU Ji-dong , LI Jun , CHEN Guang , SUN Xiong-jie.Effect of tempering temperature on microstructure and mechanical properties of AISI 6150 steel J. Cent. South Univ. (2013) 20: 866-870

[5] Y. AlizadFarzin, A. Najafizadeh, E. Hosseinkhan Nejad.Effect of temperature in intercritical treatment on microstructure, tensile properties and hardness in dual phase ST52 steel, J. Mater. Environ. Sci. 6 (5) (2015) 1716-1722.

[6] S.Z. Qamar.Effect of heat treatment on mechanical properties of H11 tool steel, , journal of Achievements in Materials and Manufacturing Engineering,August (2009).

[7] D.Chaouch, S. Guessasma, A. Sadok. Finite element simulation coupled to optimization stochastic process to assess the effect of heat treatment on the mechanical properties of 42CrMo4 steel, Materials and Design, JMAD 3815, 25 May (2011).

[8] Salemi, A. Abdollah-zadeh.The effect of tempering temperature on the mechanical properties and fracture morphology of a NiCrMoV steel, Materials Characterization.59 (2008) 484-487.

[9] C.F.Kuang, J.Li, S.G.Zhang,J.Wang, H.F.Liu, A.A.Volinsky. Effects of quenching and tempering on the microstructure and bake hardening behavior of ferrite and dual phase steels Materials Science& Engineering A613 (2014)178-183.

[10] M. Bayrak, F. Ozturk, M. Demirezen, Z. Evis. Analysis of Tempering treatment on material properties of DIN 41Cr4 and DIN 42CrMo4 Steels, Journal of Materials Engineering and Performance.16 (2007) 597-600.

[11] R. Zapała, B. Kalandyk, P. Wawro.Effect of tempering temperature on the mechanical properties of cast L35HM

steel, archives of foundry engineering volume 17, issus 2(2017), 151-156.

[12] Chukwuyem.Ikpeseni,Obimma.Basil Onyekpe, Itopa .Momoh . Effect of tempering on the microstructure and mechanical properties of austenitic dual phase steel,International, Journal of Physical Sciences,Vol. 10(16), pp. 490 - 497, 30 August (2015).

[13] R.Dziurka, J.Pacyna .The effect of carbon content on selected mechanical properties of model Mn-Cr-Mo alloy steels during tempering, Inżynieria Materiałowa, (2013).

[14] M. Gogic, L. Kosec, P. Matkovic, The effect of tempering temperature on mechanical properties and microstructure of low alloy Cr and CrMo steel, Journal of Materials Science.33 (1998) 395-403.

[15] Smoljan, D. Iljkic Simulation of mechanical properties of forged and casted steel 42CrMo4 specimen, Journal of achievements in materials and manufacturing engineering V34 (2010).

[16] R. Dziurka, J. Pacyna, T. Tokarski Effect of heating rate on the phase transformations during tempering of low carbon Cr-Mn-Mo alloy steel ,Archives of materials and science and engineering ,September (2013).

[17] A.Kokosza, Pacyna, J. Effect of retained austenite on the fracture toughness of tempered tool steel. Archives of Materials Science and Engineering, June (2008).

[18] GeorgeE.Totten .Steel Heat Treatment Handbook,Metallurgy and Technologies, Second Edition. by taylor & Francis Group, LLC,(2006)

[19] Fawad .T, Nausheen. N, Rasheed. A Baloch, Ashraf.A. Evolution of microstructure and mechanical properties during quenching and tempering of ultrahigh strength 0.3C Si-Mn-Cr-Mo low alloy steel, 5 January (2010).

[20] Mustafa Bayrak, Fahrettin Ozturk, Mehmet Demirezen, and Zafer Evis. Analysis of tempering treatment on material properties of DIN 41Cr4 and DIN 42CrMo4 steels,June 26, (2006).

[21] J. Wang, P. J. Van der wolk, S. Van der Zwaag. On the influence of alloying elements on the bainite reaction in low alloy steels during continuous cooling , Journal of materials science 35 (2000)4393 – 4404.

[22] MenevişSıcaklığınınSertleştirilmiş 1.2842 TakımÇeliğininMekanikÖzelliklerineEtkisi. Effect of tempering temperature on the mechanical properties of hardened 1.2842 tool steel, Ç.Ü Fen veMühendislikBilimleriDergisiYıl(2012) Cilt: 28-3.

[23] T. Demir, M. Ubeyli, Y. Ro, Investigation on the ballistic impact behavior of various alloys against 7.62 mm armor piercing projectile, Mater. Des.24 (2003) 503-507.

[24] Li, Z. Guangying.Intergranular fracture of low-alloy cast steel, Mater.Charact. 36 (1996) 65 -72

[25] Harry Bhadeshia, Robert Honeycombe.Steels microstructure and properties 3rdedition. Elsevier ,15th June (2006).

[26] M.J. Balart, J.F. Knott. Low temperature fracture properties of DIN 22NiMoCr37 steel in fine-grained bainite and coarse-grained tempered embrittled martensite microstructures, Engineering Fracture Mechanics.75 (8) (2008) 2400-2513.

[27] B.V. Narasimha, G. Thomas. Structure property relations and the design of Fe- 4Cr-C base structural steels for high strength and toughness, met. Trans. 11A (1980) 441- 457.

[28] B. Qin, Z.Y Wang, Q.S.Sun. Effect of tempering temperature on properties of 00Cr16Ni5Mo stainless steel. Material Characterization, August (2008), 59:1096-1100.

[29] H .Herring. The Embrittlement phenomena in hardened and tempered steel, Industrial Heating, 10, 16 -18. (2006).

[30] S.G. Druce. Effects of austenitisation heat treatment on the fracture resistance and temper embrittlement of MnMoNi steels, ActaMetallurgica.34 (2) (1986) 219 - 232.

[31] A. Kokosza, J.Pacyna. Effect of retained austenite on the fracture toughness of tempered tool steel, Archives of materials Science and Engineering, 2008,31(2): 87-90.

[32] P.K. Jena, Bidyapati Mishra, M. Ramesh Babu. Effect of heat treatment on mechanical properties and ballistic properties of ultra-high strength armour steel, International Journal of Impact Engineering 37 (2010) 242–249.

[33] ZHONG, Ping. Effect of tempering temperature on microstructure and mechanical properties in new-type ultrahigh strength steel, Journal of Iron and Steel Research, International, 288-291, September (2007).

[34] Bello .K.A, Hassan S.B and M .Abdulwahab.Effects of tempering on the microstructure and mechanical properties of low carbon, low alloy martensitic steel,Journal of Applied Sciences Research, 3(12): 1719-1723, (2007).

[35] B. London, D. V. Nelson, J. C. Shyne. The effect of tempering temperature on near- threshold fatigue crack behavior in quenched and tempered 4140 steel, October (1988).

[36] M.H. Khani Sanij, S.S. Ghasemi Banadkouki, A.R. Mashreghi, M. Moshrefifar .The effect of single and double quenching and tempering heat treatments on the microstructure and mechanical properties of AISI 4140 steel, Materials and Design 42 (2012) 339-346.

[37] P.V.Chandra Sekhar Rao ,a, A.Satya Devib, K.G.Basava Kumarc. Influence of melt treatments on dry sliding wear behavior of hypereutectic Al-15Si-4Cu Cast Alloys, Jordan journal of Mechanical and Industrial Engineering,Volume 6, Number 1, Feb. (2012).

[38] ASTM D6110, Standard Test Method for Determining the Charpy Impact Resistance of Notched Specimens.