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Received on: 22/01/2018
Accepted on: 05/04/2018
Published online: 25/10/2018

Optimization of Heat Treatment Parameters for the Tensile Properties of Medium Carbon Steel

Abstract- *The purpose of this study is designate quenching and tempering heat treatment by using Taguchi technique to determination optimal factors of heat treatment (tempering temperature, percentage of nanoparticles, type of base media, nanoparticles type and tempering time)for increasing ultimate tensile strength, yield strength and ductility properties of medium carbon steel. An (L18) orthogonal array was chosen for the design of experiment. The optimum process parameters were determined by using signal-to-noise ratio (larger is better) criterion. The importance levels of process parameters on tensile properties were obtained by using analysis of variance, which applied with the help of (Minitab18) software. Percentage of volumetric fractions of nanoparticles with three different levels(0.01, 0.03 and 0.08 %) were prepared by dispersing nanoparticles that are (α-Al2O3,TiO2 and CuO) with base fluids (De-ionized water, salt solution and engine oil).Medium carbon steel specimens were suffered to hardening and tempering heat treatment process. The variables of tempering heat treatment were temperatures (400 C˚, 550 C˚) and a soaking times (30, 45 and 60 minutes) respectively. Tensile testing performed on samples using united universal hydraulic machine. The results for (S/N) ratios showed the order of the factors in terms of the proportion of their effect on ultimate tensile strength, yield strength and ductility properties as follow: Tempering temperature (400 C˚) ,Nanoparticles type (TiO2),Tempering time (30 min),Type of base media (salt solution, engine oil) and Percentage of nanoparticles (0.03%) was the least influence for ultimate strength and yield strength while for the elongation were as follows: Tempering temperature (550 C˚),Tempering time(60min), Nanoparticles type (CuO),Type of base media (deionized water) and last percentage of nanoparticles (0.08%).*

Keywords-*Nanofluids, quenching, tempering, tensile properties, Taguchi technique.*

How to cite this article: A. Kh. Hussein, L.K. Abbas and W.N. Hasan, "Optimization of Heat Treatment Parameters for the Tensile Properties of Medium Carbon Steel, "*Engineering and Technology Journal*, Vol. 36, Part A, No. 10, pp. 1091-1099, 2018.

1. Introduction

Heat treatment is a combination of controlled heating and cooling applied to a particular metal or alloy in the solid state in such ways to produce certain microstructure and desired mechanical properties [1]. In many industrial applications, the conventional heat transfer fluids are refrigerants, water, engine oil, ethylene glycol etc. Heat transfer is amongst the vital industrial processes. In any industry, heat must be efficiently managed by adding, removing or moving in the relevant sectors. There are several methods to improve the heat transfer efficiency; of these methods are utilization of extended Nano fluids [2]. Nano fluid it is a mixture/suspension of the base liquid and nanoparticles with a size below 100 nm [3]. Base fluids can be water, ethylene glycol, polyalkylene glycol (PAG) or quenching oil, while metal Nano powders (Cu, Au, Ag), oxide-ceramic particles (Al_2O_3, SiO_2, TiO_2), carbon powders and nanotubes are added to a base fluid [4,5,6]. Numerous experimental and theoretical studies had been reported in literature to evaluate enhancement in thermal conductivity of Nano fluids. According to Keblinski et al. enhancement in thermal conductivity was found to be 40% only by dispersing (1vol%) Cu nanoparticles in ethylene glycol [7].Thermal conductivity enhancement of (MWCNTs/Water) Nano fluids was found to be (11.3%) at (1vol%) [8]. Zhu et al. reported (18%, 28% and 31%) enhancement in thermal conductivity at (1, 3 and 5vol%)respectively for (CuO/Water)Nano fluid [9]. Determination of the heat treatment parameters optimization is necessary to optimize the mechanical property, to

https://doi.org/10.30684/etj.36.10A.10
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achieved that Taguchi method was used. The aim of parametric design experiment is to identify and design the process parameters to optimize the chosen quality characteristics that are least sensitive to noise factors [10,11]. The main aim of this study is determination of the optimum quenching and tempering heat treatment parameters in order to improving ultimate strength, yield strength and elongation properties.

2. Experimental Procedure

I. Materials

The following materials were used in the Nano fluids synthesis:
Nano titanium dioxide (TiO_2) powder, Nano aluminum oxide(α-Al_2O_3) powder and copper oxide (CuO) nanoparticle (supplied by Zhengzhou DongyaoNano materials Co.LTD.). The properties of these nanoparticles are given on Table 1. Those materials were added to base media (Deionized water, Salt solution (NaCl+water) and Engine oil). Sodium lauryl sulphate as surfactant was used.

Table 1: Physical properties of nanoparticles

Nanoparticle material	APS (nm)	Purity (%)	Specific surface area (m2/g)	Volume density (g/cm3)	Density (g/cm3)	Crystal form	Color
α-Al2O3	50	>99.99	160.1	0.916	3.91	γ	white
TiO2	20	>99.9	220	0.25	3.9	Cube	white
CuO	50	>99.9	120	0.30-0.45	6.40	Sphere	black

II. Nano fluid Preparation

In this research, eighteen types of Nano fluid are prepared [(Al_2O_3/ Deionized water), (Al_2O_3/ salt solution), (Al_2O_3/ engine oil)], [(TiO_2/ De ionized water),(TiO_2/ salt solution), (TiO_2/ engine oil)], [(CuO/ De ionized water), (CuO / salt solution), (Cuo / engine oil)] with volume fractions of (0.01, 0.03 and 0.08%). In this paper Nano fluid was prepared by two step method where the given nanoparticle is mixed to the base fluid to obtain suspension. Law of mixtures was employed to determination quantity of nanoparticles wanted for preparation of Nano fluids. The mass of nanoparticles (M_p) and base fluid (M_f) are measured with balance of (0.0001 g) an accuracy. The weight percentage (ϕ) can be calculated by using Eq (1).

$$\phi = \frac{M_{np}/\rho_{np}}{\frac{M_{np}}{\rho_{np}} + \frac{M_{bf}}{M_{bf}}} \quad (1)$$

Where,

Φ: volume fraction.
M_{np}: mass of nanoparticle(g).
ρ_{np}: density of the nanoparticle(g/L).
M_{bf}: mass of the base fluid (g).
ρ_{bf}: density of the base fluid(g/L).[12]

A mechanical stirrer was used to achieve a homogenously dispersed solution, as shown in Figure (1-C). This method was based on Han and Rhi [13] and Mahendran et al. [14]. After preparing the proper mix of the nanoparticles and fluids by mechanical stirrer, nanoparticles are dispersed in fluids using magnetic stirrer Figure (1-A). During the process Sodium Dodecyl Sulphate (SDS) surfactant is added to the solution in proper proportions to ensure stability of Nanofluid.For various purposes, sound energy is used to agitate the particles in Nano fluid, this process is known as sonication. By breaking intermolecular interaction, sonication is also used for speed up the dissolution. Sonication is more useful when the magnetic stirring was not much effective for given sample. For nanoparticles which were not evenly dispersing in liquids, sonication is most preferable. The sonication process is achieved in two steps were:

1- Initially Sonicate the mixture continuously for (30 min) with sonicator to obtain uniform dispersion of nanoparticles in fluids, this process is achieved with ultrasonic mixer (LUC – 410(50 Hz,400W)) that shown in Figure (1-B).

2-Sonicate the mixture continuously for (90 min) with probe sonicator that shown in Figure (1-D).

Figure 1: A-Magnetic stirrer, B- Ultrasonic or bath sonicator C-Electrical blender, D-Ultra sonicator probe sonicator

III. Material of the research specimens

The medium carbon steel specimens were taken for this project. The chemical composition analysis of the specimens was carried out at the (General Company for Engineering inspection and Rehabilitation) by x-ray fluorescent. The chemical composition of the medium carbon steel is shown in Table 2.

Table 2: The chemical composition of medium carbon steel specimens

Element	Composition %
C%	0.583
Si%	1.76
Mn%	0.790
P%	0.0197
S%	0.0035
Cr%	0.0351
Mo%	0.002
Ni%	0.0135
Al%	0.0264
Cu%	0.033
Fe%	Bat

IV. Specimen preparations

The first and main step is the preparation of samples for tensile testing. The eighteen steel samples were machined using (CNC) machine to standard dimensions according to (ASTM E8), and then the specimens were grinded and polished.

V. Heat Treatment process

Eighteen different heat treatments were performed; these were quenched and tempered according to Schedule (4). Quenching heat treatment was implemented to harden the medium carbon steel. Quenching heat treatment includes heating of samples to austenitizing temperature in furnace where the samples was held at (900°C) for appropriate time (1 hour) to ensure uniformity of temperature throughout the full volume to attain a identical structure of austenite, subsequently each group of samples were quenched in diverse quenching mediums (Nano fluids).Then the samples were subjected to tempering process which included reheating quenched steel with (400 and 550C°) temperatures with a soaking time were (30,45 and 60 min) and then allowed to cool down gradually.

VI. Ultimate Tensile Strength Testing

For execution tensile test of the samples (United Universal Hydraulic) machine was used for get the following mechanical properties: the percentage of elongation, ultimate tensile strength, yields strength. These properties were calculated by utilizing the following formulas: [15].

$$\%EL \frac{\text{Change in guage length of specimen}}{\text{initial guage length of the specimen}} \quad (2)$$

$$Y.S = \frac{\text{load at 0.2\%offset yield}}{\text{initial cross section area}} \quad (3)$$

$$U.T.S = \frac{\text{maximum load}}{\text{initial cross section area}} \quad (4)$$

3. Taguchi method

The Taguchi method is a robust tool for designing high quality systems based on orthogonal array experiments that provide much-reduced variance for experiments with an optimum setting of process control parameters [16,17]. Some of its many advantages include:(1) Designs Orthogonal arrays (OA) to balance process parameters and minimize test runs. (2) Employs signal-to-noise (S/N) ratio to analyze experiment data, and conclude more information. (3) Estimates individual parameter contributions [16,17,18].

4. Design of Experiment

The experimental program worked out considering parameters (variables) and levels as shown in Table 3 based on the Taguchi technique. Tempering temperature, percentage of nanoparticles, type of base media, nanoparticles type and tempering time, these process parameters considered for this study. In the present investigation, an (L18) orthogonal array was chosen as shown in Table 4. The experimental results were transformed into signal-to-noise ratio (S/N). The (S/N) ratio for the (ultimate strength, yield strength and elongation) using "Larger the better" characteristics, which can be calculated as logarithmic transformation of the loss function is given as [19].

Larger the Better (LTB)

$$\frac{S}{N} = -10 log 101/n \sum[1/Y_i^2] \quad (5)$$

5. Results and Discussions

I. S/N Ratios Analysis

The (S/N) ratio response was analyzed using the equation (5) for all Eighteen tests and presented in Table 4. Figure 2 and Table 5 shows the main effects plots of (S/N) ratios for ultimate strength, yield strength and elongation. From the Figure 2 and Table 5 it is evident that the order of factors by effect was as follows tempering temperature, nanoparticles type, tempering time, type of base media and last percentage of nanoparticles for ultimate strength and yield strength while for the elongation were as follows tempering temperature, tempering time, nanoparticles type, type of base media, and last percentage of nanoparticles.

Table 3: Control factors and their levels

Symbol	Control factors	Levels			Unit
A	Tempering temperature	400	550	-----	oC
B	Concentration media	0.01%	0.03%	0.08%	-----
C	base media	Deionized water	Salt solution	Engine oil	-----
D	Nano particles type	α-Al2O3	TiO2	CuO	-----
E	Tempering time	30	45	60	min

II. ANOVA Analysis

To analyze the influence of parameters (tempering temperature, percentage of nanoparticles, type of base media, nanoparticles type and tempering time) on the ultimate strength, yield strength and elongation properties (ANOVA) was used. The (ANOVA) determines the relative significances of factors in expressions of their percentage contribution to the response[20].We can observe from the (ANOVA) analysis (Table 6) that the ranking of parameters according to its influence on the total variation were as follows tempering temperature, nanoparticles type, tempering time, type of base media and last percentage of nanoparticles for ultimate strength and yield strength while for the elongation were as follows tempering temperature , tempering time, nanoparticles type, type of base media, and last percentage of nanoparticles.

III. Regression Equation

A Regression model is developed using statistical software (MINITAB 18). This model gives the relationship between an independent/predicted variable and a response variable by fitting linear equations to observe data. Regressions equation create establishes correlations between the significant terms acquired from (ANOVA) analysis namely (tempering temperature, percentage of volume fraction of nanoparticles, base media, type of nanoparticles and tempering time).

Table 4: Signal to Noise Ratios for the controlling factors considering Ultimate strength, Yield strength and Elongation

Expt	Parameters					Ultimate strength (N/mm2)	S/N for Ultimate strength	Yield strength(N/mm2)	S/N for Yield strength	Elongation %	S/N for Elongation
	A	B	C	D	E						
1	400	0.01	Deionized water	α-Al_2O_3	30	2256	67.1	1627	64.2	7.5	17.5
2	400	0.01	Salt Solution	TiO_2	45	2188	66.8	1559	63.9	8.3	18.4
3	400	0.01	Engine oil	CuO	60	2180	66.8	1510	63.6	8.8	18.9
4	400	0.03	Deionized water	α-Al_2O_3	45	2061	66.3	1432	63.1	9.2	19.3
5	400	0.03	Salt Solution	TiO_2	60	2233	67.0	1604	64.1	8.1	18.2
6	400	0.03	Engine oil	CuO	30	2160	66.7	1531	63.7	8.8	18.9
7	400	0.08	Deionized water	TiO_2	30	2170	66.7	1517	63.6	8.3	18.4
8	400	0.08	Salt Solution	CuO	45	2175	66.8	1566	63.9	8.3	18.4
9	400	0.08	Engine oil	α-Al_2O_3	60	1990	66.0	1361	62.7	10.7	20.6
10	550	0.01	Deionized water	CuO	60	1410	63.0	809	58.2	19.7	25.9
11	550	0.01	Salt Solution	α-Al_2O_3	30	1565	63.9	951	59.6	15.3	23.7
12	550	0.01	Engine oil	TiO_2	45	1599	64.1	970	59.7	16	24.1
13	550	0.03	Deionized water	TiO_2	60	1618	64.2	989	59.9	15.6	23.9
14	550	0.03	Salt Solution	CuO	30	1603	64.1	974	59.8	16	24.1
15	550	0.03	Engine oil	α-Al_2O_3	45	1573	63.9	949	59.6	16.6	24.4
16	550	0.08	Deionized water	CuO	45	1480	63.4	886	59.0	18	25.1
17	550	0.08	Salt Solution	α-Al_2O_3	60	1594	64.1	965	59.7	16.4	24.3
18	550	0.08	Engine oil	TiO_2	30	1660	64.4	1031	60.3	14.6	23.3

Table 5: Responses table for SN ratio-(Ultimate strength, Yield strength and Elongation)

Ultimate strength	Factor A	Factor B	Factor C	Factor D	Factor E
Level 1	66.67119	65.26475	65.10779	65.20001	65.47936
Level 2	63.89129	65.3602	65.42777	65.52777	65.20808
Level 3		65.21877	65.42777	65.11595	65.15628
Delta	2.779899	0.141437	0.319984	0.411823	0.323081
Rank	1	5	4	2	3
Yield strength	Factor A	Factor B	Factor C	Factor D	Factor E
Level 1	63.64215	61.52037	61.32965	61.47054	61.85782
Level 2	59.5092	61.69048	61.8137	61.91421	61.51684
Level 3		61.51618	61.8137	61.34228	61.35237
Delta	4.132948	0.174296	0.484048	0.571926	0.50545
Rank	1	5	4	2	3
Elongation	Factor A	Factor B	Factor C	Factor D	Factor E
Level 1	18.71759	21.40633	21.6693	21.62625	20.97262
Level 2	24.30022	21.44703	21.16765	21.02746	21.60482
Level 3		21.67336	21.16765	21.87301	21.94929
Delta	5.582627	0.226337	0.501647	0.845545	0.976666
Rank	1	5	4	3	2

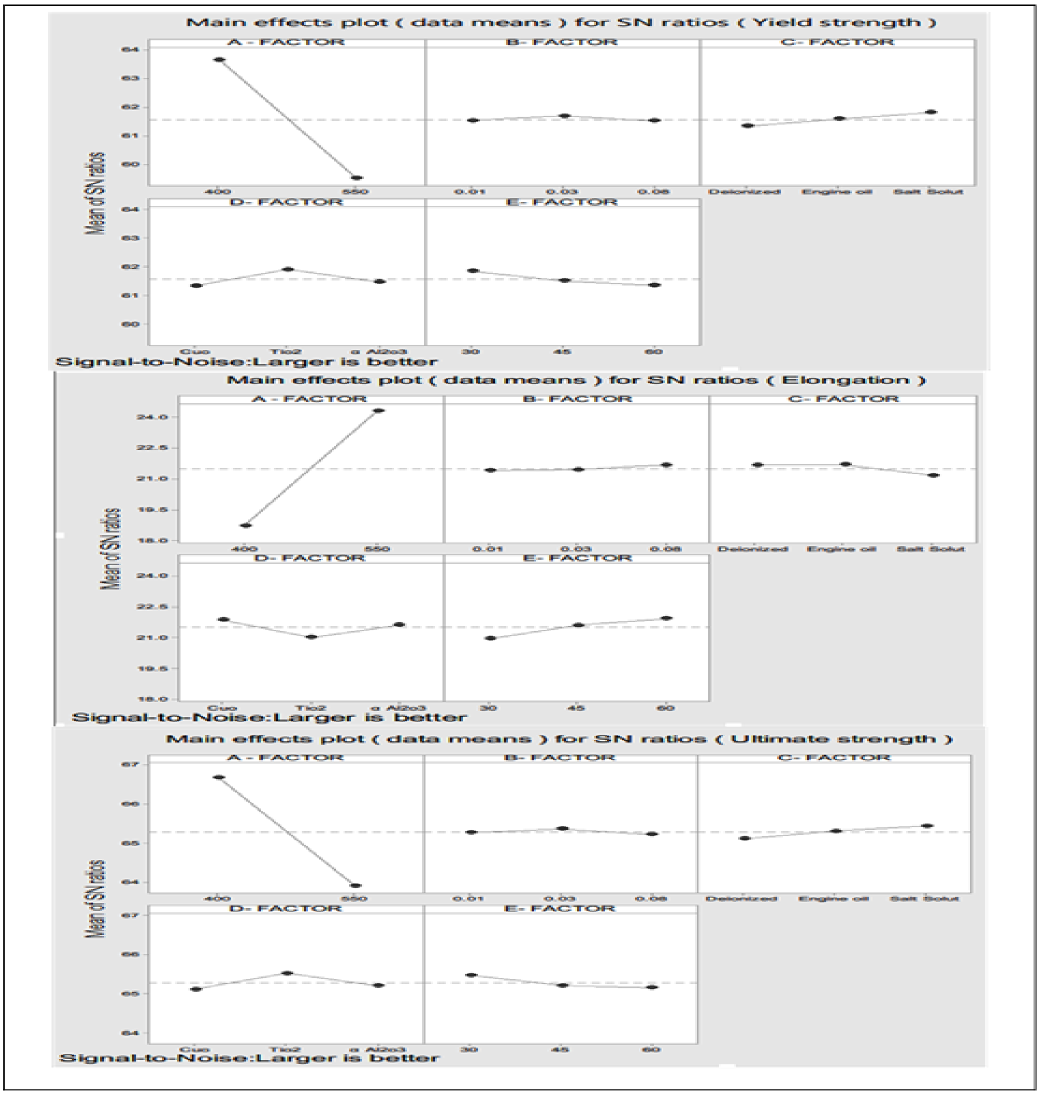

Figure 2: Main effects plots for SN ratios-(Ultimate strength, Yield strength and Elongation)

Table 6: Results of the (ANOVA). (Ultimate strength, Yield strength and Elongation)

Source	DF	SeqSS	Adj MS	F-Value	P-Value	% of contribution
Ultimate strength						
A	1	1566647	1566647	248.19	3.88E-05	93.92475
B	2	2815	1408	0.22	2.6E-07	0.168767
C	2	11024	5512	0.87	0.80493	0.660919
D	2	22052	11026	1.75	0.453919	1.322077
E	2	14946	7473	1.18	0.23472	0.896053
Error	8	50497	6312		0.354489	3.027433
Total	17	1667981				100
Yield strength						
Source	DF	SeqSS	AdjMS	F-value	P-Value	% of contribution
A	1	1492416	1492416	267.81	2.94E-05	94.4018
B	2	2012	1006	0.18	2E-07	0.127268
C	2	11591	5795	1.04	0.838134	0.733181
D	2	16863	8432	1.51	0.396764	1.066658
E	2	13455	6727	1.21	0.277126	0.851087
Error	8	44582	5573		0.348195	2.820005
Total	17	1580919				100
Elongation						
Source	DF	SeqSS	AdjMS	F-value	P-Value	% of contribution
A	1	273.78	273.78	240.16	3.98E-05	91.51013
B	2	0.343	0.172	0.15	3E-07	0.114647
C	2	2.903	1.452	1.27	0.862587	0.970319
D	2	6.33	3.165	2.78	0.331039	2.115783
E	2	6.703	3.352	2.94	0.121413	2.240457
Error	8	9.12	1.14		0.110354	3.048332
Total	17	299.18				100

Table 7: Regression equations of (Ultimate strength, Yield strength and Elongation)

Ultimate strength=	1862.0 + 295.0 A - FACTOR_400 - 295.0 A - FACTOR_550 + 4.4 B- FACTOR_0.01+ 12.6 B- FACTOR_0.03 - 17.0 B- FACTOR_0.08 - 29.5 C- FACTOR_Deionized water - 1.6 C- FACTOR_Engine oil + 31.1 C- FACTOR_Salt Solution- 27.3 D- FACTOR_Cuo + 49.4 D- FACTOR_Tio2 - 22.1 D- FACTOR_α Al2o3+ 40.5 E- FACTOR_30 - 16.0 E- FACTOR_45 - 24.4 E- FACTOR_60
Yield strength =	1514.9 + 0.0 A - FACTOR_400 - 575.9 A - FACTOR_550 + 0.0 B- FACTOR_0.01 + 8.8 B- FACTOR_0.03 - 16.7 B- FACTOR_0.08 + 0.0 C- FACTOR_Deionized water+ 15.3 C- FACTOR_Engine oil + 59.8 C- FACTOR_Salt Solution + 0.0 D- FACTOR_Cuo + 65.7 D- FACTOR_Tio2 + 1.5 D- FACTOR_α Al2o3 + 0.0 E- FACTOR_30 - 44.8 E- FACTOR_45 - 65.5 E- FACTOR_60
Elongation =	12.567 - 3.900 A - FACTOR_400 + 3.900 A - FACTOR_550 + 0.033 B- FACTOR_0.01- 0.183 B- FACTOR_0.03 + 0.150 B- FACTOR_0.08 + 0.483 C- FACTOR_Deionized water + 0.017 C- FACTOR_Engine oil - 0.500 C- FACTOR_Salt Solution+ 0.700 D- FACTOR_Cuo - 0.750 D- FACTOR_Tio2 + 0.050 D- FACTOR_α Al2o3- 0.817 E- FACTOR_30 + 0.167 E- FACTOR_45 + 0.650 E- FACTOR_60

IV. Model Summary

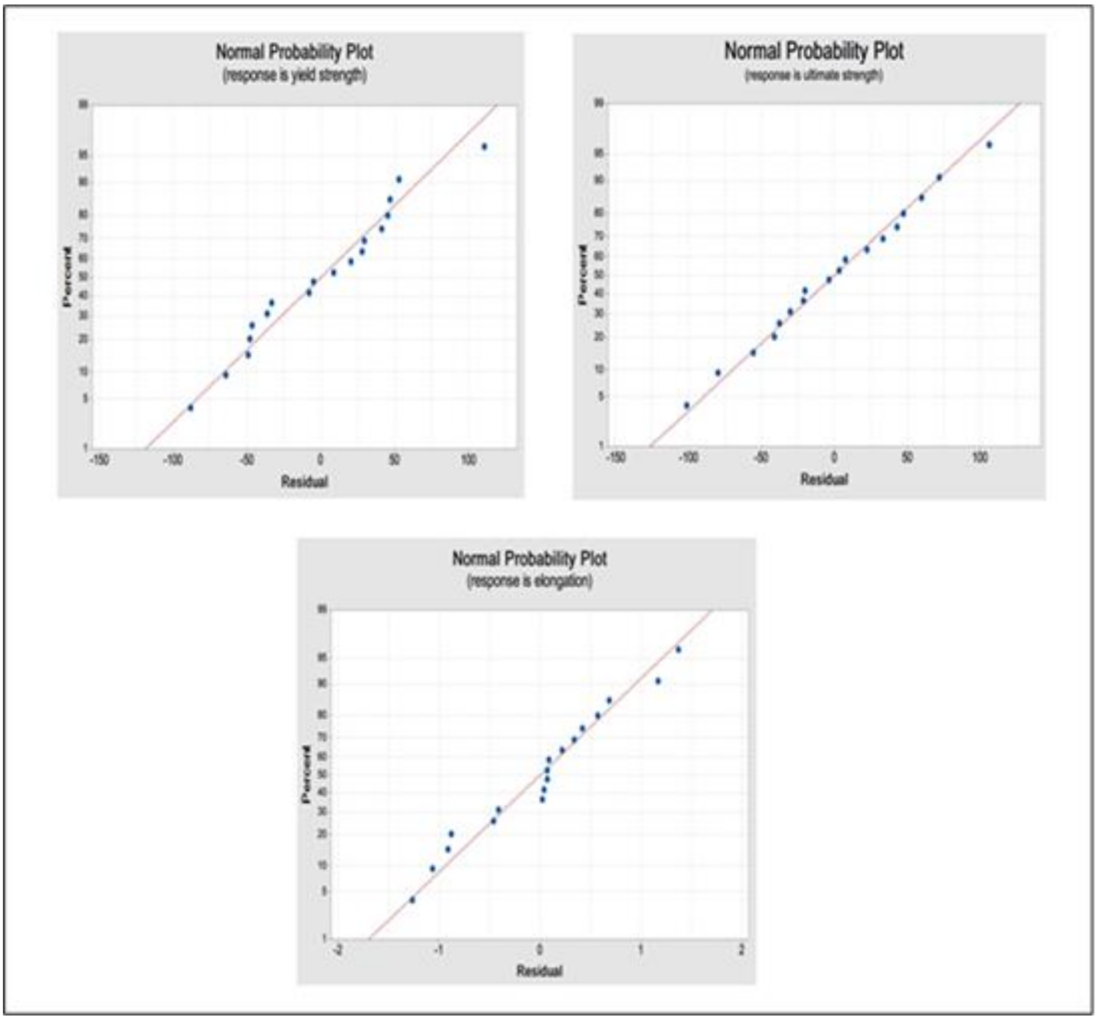

Figure 3: Normal probability plot of residuals (ultimate strength, yield strength and elongation)

The graph (3) shows that the data closely follow the straight lines, denoting a normal distribution.

Table 8: Model summary of (Ultimate strength, Yield strength and Elongation)

Ultimate strength			
S	R-sq	R-sq(adj)	R-sq(pred)
79.4492	96.97%	93.57%	84.67%
Yield strength			
S	R-sq	R-sq(adj)	R-sq(pred)
74.6507	97.18%	94.01%	85.72%
Elongation			
S	R-sq	R-sq(adj)	R-sq(pred)
1.06771	96.95%	93.52%	84.57%

6. Conclusions

Determination of optimal quenching and tempering heat treatment of medium carbon steel parameters is one of the most important elements to obtain the desired properties.The Taguchi method was successfully applied to determine the optimal values of tempering temperature, percentage of nanoparticles, type of base media, nanoparticles type and tempering time in order to maximize the ultimate strength, yield strength and elongation.From response table for (S/N) ratio with respect to the ultimate strength, yield strength and elongation (LTB) we can marked on the most important factor where the ranking of factors were as follows tempering temperature (400 C˚),nanoparticles type (TiO_2), tempering time (30 min), type of base media (salt solution ,engine oil) and last percentage of nanoparticles (0.03 %) according to the its importance for ultimate strength, yield strength while for the elongation were as follows tempering temperature (550 C˚), tempering time (60 min) ,nanoparticles type (CuO), type of base media (deionized water), and last percentage of nanoparticles (0.08 %).

References

[1] M.S. Htun, S.T. kyaw, K.T. Lwin, "Effect of Heat Treatment on Microstructures and Mechanical Properties of Spring Steel," Journal of Metals, Materials and Minerals, Vol. 18, No. 2, PP. 191-197, 2008.

[2] A. Abhang, S. Sonawane, S. Avhad, A. Kakade, B.M. Dusane, "A review on synthesis mechanism and utilization of nanofluids," International Journal of Advance Research in Science and Engineering, Vol. 5, No. 2, PP.491-499, 2016.

[3] S. Lee, S. U. S. Choi, S. Li, J. A. Eastman, "Measuring thermal conductivity of fluids containing oxidienanoparticles, "ASME Journal of Heat Transfer, Vol. 121, No. 2, PP. 280-289, 1999.

[4] J.T. Cieliski, T. Kaczmarczyk, "Pool boiling of water-Al2O3 and water-Cu nanofluids on horizontal smooth tubes," Nanoscale Research Letters (aspring open journal), Vol. 220, No. 6, PP.1-9, 2011.

[5] J.T. Cieliski, T. Kaczmarczyk, "Pool boiling of water-Al_2O_3 and water-Cu nanofluids on porous coated tubes," Journal Heat Transfer Engineering, Vol. 36, No. 6, 2015.

[6] J. Zupan, D.L Andek, T. Filetin, "Investigation of the cooling process with nanofluids according to ISO 9950 and ASTM D 6482 standards," Journal Materials and technology, Vol. 47, No.1, PP. 125-127, 2013.

[7] P. Keblinski, J.A. Eastman, D.G. Cahill, "Nanofluids for thermal transport," Journal Materials Today, Vol. 8, No. 6, PP.36-44, 2005.

[8] Y. Hwang, H.S. Park, J.K. Lee, W.H. Jung, "Thermal conductivity and lubrication characteristics of nanofluids," Journal Current Applied Physics, Vol. 6, No. 1, PP.67-71, 2006.

[9] H.T. Zhu, C.Y. Zhang, Y.M. Tang, J. Wang, "Novel synthesis and thermal conductivity of CuO nanofluid," Journal Physics Chemistry, Vol. 111, No. 4, PP.1646–1650, 2007.

[10] K. Raghu, "Off-Line Quality Control, Parameter Design, and the Taguchi Method," Journal of Quality Technology, Vol. 17, No. 4, PP.176-188, 1985.

[11] P.K. Chaulia, R. Das, "Process Parameter optimization for Fly Ash Brick by Taguchi Method," Journal Materials Research, Vol. 11, No. 2, PP.159-164, 2008.

[12] 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 (IJETT), Vol. 9, No. 15, PP.798-800, 2014.

[13] W.S. Han, S.H. Rhi, "Thermal characteristics of grooved heat pipe with hybrid nanofluids," Journal Thermal Science, Vol. 15, No. 1, PP.195-206, 2011.

[14] M. Mahendran, G.C. Lee, K.V. Sharma,, A. Shahrani, R.A. Bakar, "Performance of evacuated tube solar collector using water-based titanium oxide (TiO_2) nanofluid," Journal of Mechanical Engineering and Sciences, Vol. 3, PP.301-310, 2012.

[15] B.K. Azmite, A.A. Werkneh, A.T. Abebe, "An experimental study on the mechanical characteristics of low alloy carbon steels forbetter performance of traditional farm implements in Ethiopia," International Journal of Materials Science and Applications, Vol. 3, No. 6, PP.420-430, 2014.

[16] C.C. Chang, J.G. Yang, C. Ling, C.P. Chou, "Optimization of Heat Treatment Parameters with the Taguchi Method for the A7050 Aluminum Alloy," IACSIT International Journal of Engineering and Technology, Vol. 2, No. 3, PP.269-272, 2010.

[17] A.K. Hussein, "Taguchi Approach to Optimize Pack Aluminization Parameters in Carbon Steel Using MINITAB13," Eng. & Tech. Journal, Vol. 27, No. 11, PP.2259-2272, 2009.

[18] R.M. Singari, V.S. Gupta, "Prediction of Surface Roughness in CNC Turning of Aluminum 6061 Using Taguchi Method and ANOVA for the Effect of Tool Geometry," International Journal of Advanced Production and Industrial Engineering, Vol. 1, No. 1, PP.22-27, 2016.

[19] A. Çiçek, T. Kıvak, G. Samtaş, "Application of Taguchi Method for Surface Roughness and Roundness Error in Drilling of AISI 316 Stainless Steel," Journal of Mechanical Engineering, Vol. 58, No. 3, PP.165-174, 2012.

[20] A.K. Hussein, L.K. Abbas, N.J. Ismae, "Modeling of Carburization Parameters Process for Low Carbon Steel," Eng. & Tech. Journal, Vol. 34, No. 6, PP.1069-1079, 2016.