

# Artificial Neural Network Based Study of Impact of Austenitizing on the Toughness of Hot Die Steel

Rajnish Shandil and Mehar Chand  
Green Hills Engineering College Kumarhatti Solan  
Himachal Pradesh Technical University, Hamirpur

*Corresponding Author: Rajnish Shandil*  
Assistant Professor

---

## ABSTRACT

The Artificial Neural network (Neural Net or ANN for short) could be assortment of straight forward processors connected along. Every processor will solely perform a really simple mathematical task. A number of adaptive numerical modeling methods applied to an intensive reasonably regression and complications problems in materials science similar to support vector machines, artificial neural networks and mathematician processes. There is no direct relation between toughness and grain size along with different heat treatment temperature. To find the relation among these parameters, artificial neural network (ANN) model is set up which provides prediction of toughness and grain size w.r.t. different heat treatment temperature. ANN as mathematical tool is useful in analysis and prediction of the properties and limited number of measurement results utilized for the prediction and analysis.

**Keywords** – Artificial neural network (ANN), Grain size, tool steels

---

Date of Submission: 01-03-2023

Date of acceptance: 11-03-2023

---

## I. INTRODUCTION

Tool steel is a kind of steel used to manufacture tools for forming, cutting and molding a material into a section, component or part utilize for definite purpose. The addition of alloying elements like Molybdenum, Tungsten, Chromium and Manganese could empower tool steel to meet thorough rigorous services and can give more dimensional stability and independence from cracking while undergoing heat treatment processes. The performance of a tool utilized in service totally relies on the accuracy with which the tool is made, the selection of heat treatment process, the design of the tool and the selection of tool steel. High quality tool steel, proper design, and appropriate manufacturing methods are the important factors are required and determining the procedures of the heat treatment.

### 1.1 Tool steel

Tool steel is a kind of steel used to manufacture tools for forming, cutting and molding a material into a section, component or part utilize for definite purpose. The addition of alloying elements like Molybdenum, Tungsten, Chromium and Manganese could empower tool steel to meet thorough rigorous services and can give more dimensional stability and independence from cracking while undergoing heat treatment processes. The performance of a tool utilized in service totally relies on the accuracy with which the tool is made, the selection of heat treatment process, the design of the tool and the selection of tool steel. High quality tool steel, proper design, and appropriate manufacturing methods are the important factors are required and determining the procedures of the heat treatment.

#### 1.1.1 Categories of Tool Steel

The tool steel can be categorized into small number of groups, relative to their use and application-based selection. Due to steel has various alloy composition; it has been difficult to fit the steel into particular category of alloy steel. The amounts of alloying elements present in the steel have narrow limit and all categories of steels are based on carbon content variation. The American Iron and Steel Institute (AISI) and Society for Automotive Engineers (SAE) have described method for categorization of tool steel. The AISI is more popular and provide easy and simple understandable way to different categories the tool steel. The AISI classification organizes tool steels into various groups based on important characteristics like application (for example, cold-work or hot-work), heat treatment (for example oil hardening or water-hardening tool steel) and

alloying element present (for example Molybdenum, Tungsten, Manganese and Chromium alloying content). The tool steel classification and various symbol specified by AISI for each steel type is presented in Table 1.

Table 1 Tool steel types and symbols assign by AISI.

Steel Type	Symbol specified
Water strengthening tool steels	W
Shock resisting tool steels	S
Mould production tool steels	P
Special purpose tool steels	L and F
Cold-work tool steels	O, A and D
Hot-work tool steels	H
High speed tool steels	T and M

The water strengthening tool steel comes under class W, having the small alloy contents and inferior strength of this kind of tool steel. Therefore, the W tool steels normally require heat treatment like water quenching process and thick pieces harden merely to superficial depths. Thin pieces of W steel can harden by only oil quenching to reduce distortion and cracking by quenching. The shock resistant tool steels come under AISI class S, have lesser carbon percentage and relatively greater alloy percentage than that of W class steels. The toughness improved by medium carbon content and produces the class S type of steels which is excellent for applications with impact and shock loading. In cold work tool there are three classes of steels comprising of: AISI class D, O and A. All of these classes retain high content of carbon for high wear resistance and high hardness in cold work applications. However different alloying content used which affect harden ability and carbide particle distributed into hardened microstructure. The AISI class P type tool steels are utilized for making dies to mould plastic products. The P type of tool steel going through low severe wear than metal-working steel, and thus retain low carbon content. As a result of, this steel has excellent surface finish and polish ability. In H-type of tool steel have Tungsten, Molybdenum or Chromium as major alloying element. This steel is termed as hot working tool steel as it is used in elevated temperature application. Consequently, the high-speed tool steels are able of hold hardness at elevated temperatures and are broadly utilized for high-speed machining or cutting and dies uses.

### 1.1.2 Chemical Compositions of Tool Steels

Chemical composition is the most imperative impact after cutting performance of the tool steel. All alloying component in tool steel (for example, Vanadium, Tungsten, Molybdenum, Chromium) decide the mechanical properties. For hot work tool steels and high-carbon high-chromium tool steels, moderate cooling during solidification produce large content of carbide of different alloys and eutectic mixture of austenite and carbide element deposited during the melting. This mixture is difficult to broken up in solidification form and only can be done by machining. These carbides are brittle in nature and their uneven distribution affects the steel to retain limited elastic property and also distinction in chemical composition.

### 1.2 Heat Treatment of Tool Steel

Mechanical properties of tool steel are largely affected by the heat treatment. Figure 1 shows generalized heat treatment schedule that is applied to tool steel. To harden the tool steel austenitizing is the most critical factor. In the step of austenitizing the absolute alloy content is subdivided between the retained carbides and austenitic matrix (martensite formed). The volume fraction and dispersion of the retained carbides controlled during the subdivision of austenitizing. The wear resistance and austenitic grain size controls by alloy carbide produce in steel. The grain growth of austenite controlled more easily with fine carbides elements.

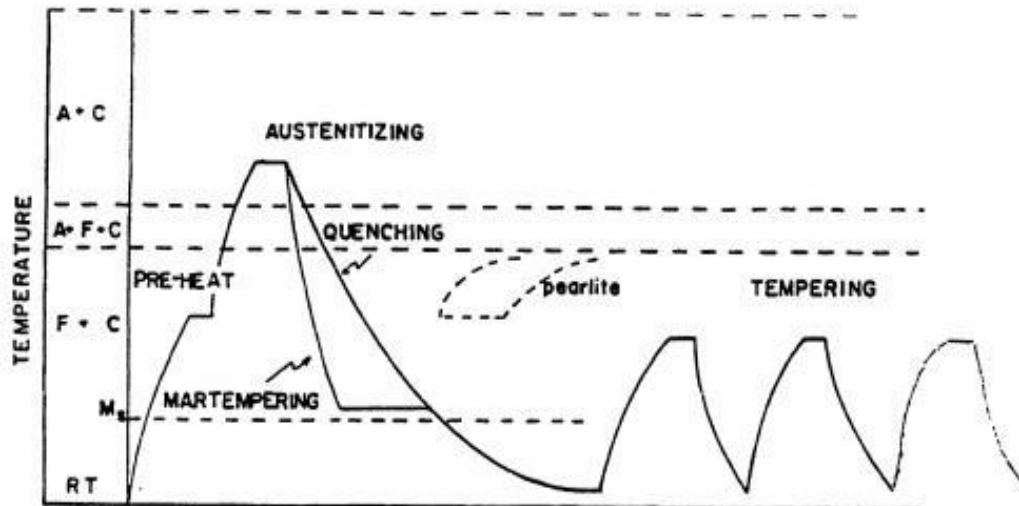


Figure 1 Schematic diagram shows steps for final hardening of tool steel

The carbide dissolved up to large extent when steel is heated at elevated austenitizing temperature and upon cooling coarse grain boundaries form as a result of cementite precipitate formed at high amount. The round particle remained in the martensite matrix as partial carbide dissolved and carbide particle stick to the pre-existing point in matrix, and network of cementite will not form at the surrounding of grain boundaries.

### 1.3 Artificial neural networking

The Artificial Neural network (Neural Net or ANN for short) could be assortment of straightforward processors connected along. Every processor will solely perform a really simple mathematical task; however, an outsized network of them has a lot of bigger capabilities and may do several things that one on its own cannot. The inspiration for the Neural net is the human brain. There are a hundred billion process units in the brain of human which are interconnected each other in the form of network. The need to mimic some of these jobs has inspired the improvement of artificial neural networks. A number of adaptive numerical modeling methods applied to an intensive reasonably regression and complications problems in materials science similar to support vector machines, artificial neural networks and mathematician processes.

### 1.4 Equipment Used

#### 1.4.1 Vacuum Furnace

Horizontal Vacuum Furnace is known to have a sturdy cold wall as a structure with a metallic or graphite hot zone. Having sliding doors, material is loaded from front of horizontal heat furnace ensuring uniformity throughout the chamber. These furnaces have excellent process parameters and support various job loads and sizes. Complete automation is possible for vacuum and heating cycles.

#### 1.4.2 Polishing machine

Polishing machine a single disc machine with variable speed and single AC motor. The metallographic samples can be polished using polishing machine. The polishing of the sample is carried out for the purpose of studying metal structure. Polishing machine rotating disk with motor drive used to attach the emery paper of various grade such as 400, 600, 800, 1200, 2000, 2500 and 3000 grade.

#### 1.4.3 Izod V Notch Impact Strength Testing

Izod impact strength test is a standard method to determine the impact resistance of material. The pivoting arm is raised to specific height and then released. The arm swings down hitting the sample and braking the specimen. The notched sample is generally used to determine the impact energy and notch sensitivity.

#### 1.4.4 Scanning Electron Microscope

The ESEM Quanta 450 FEG is a versatile scanning electron microscope with three imaging modes. The “high vacuum mode”(HV) is a conventional SEM mode with a need of conventional specimen preparation. In the “low vacuum mode”(LV) electrically non conductive samples can be imaged without the need of conductive layer.

## II. RESULTS AND DISCUSSION

The treatment processes were performed to acquire desirable mechanical properties. Quenching and tempering were carried out to optimize the value of toughness and hardness. Quenching process carried out on three different austenitizing temperature 1010°C, 1030°C and 1050°C and corresponding twice tempered at 540°C and 580°C and one sample without performing tempering at each austenitizing temperature. After Heat

treatment was done, toughness test and grain size measurement were carried out using impact taster and Scanning electron microscope respectively. There was non-linear variation of toughness and grain size with respect to austenitizing temperature, therefore a model was developed to provide a relation and predict the response variable corresponding to austenitizing and tempering temperature.

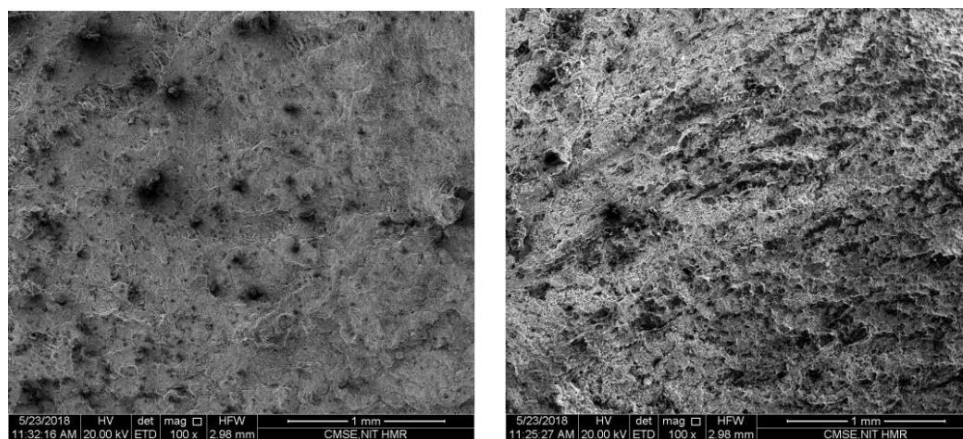
Table 2 Experimental results of grain size and toughness at different set of austenitizing and tempering temperature.

Sr.No.	Austenitizing temperature(°C)	Tempering temperature(°C)	Grain size (µm)	Toughness (J)
1	1010	As quench	7	13.7293
2	1010	540	6.5	16.6713
3	1010	580	5.9	19.6133
4	1030	As quench	9	11.2776
5	1030	540	8.9	12.7486
6	1030	580	8.1	13.7293
7	1050	As quench	10.0	10.7873
8	1050	540	9.0	15.6906
9	1050	580	8.9	17.6520
10	1010	As quench	7.1	14.0254
11	1010	540	6.4	16.2544
12	1010	580	6.0	18.9532
13	1030	As quench	8.9	11.0154
14		1030 540	8.5	12.9802
15		1030 580	8.1	14.2546
16		1050 As quench	10.0	10.2258
17		1050 540	9.5	16.1249
18		1050 580	8.5	18.1845
19		1010 As quench	7.6	12.9562
20		1010 540	7.1	16.2596
21		1010 580	5.9	20.0159
22		1030 As quench	9.8	11.6542
23		1030 540	9.5	13.0115
24		1030 580	8.1	13.9543
25		1050 As quench	10.2	10.9857
26		1050 540	9.4	15.0254
27		1050 580	8.2	17.2654
28		1010 As quench	6.9	13.2564
29		1010 540	6.4	17.0659
30		1010 580	5.4	20.3654
31		1030 As quench	8.4	11.6598
32		1030 540	8.1	12.9543
33		1030 580	7.9	14.2546
34		1050 As quench	9.7	10.0264
35		1050 540	9.0	16.2541
36		1050 580	8.9	17.9542
37		1010 As quench	6.5	12.0254
38		1010 540	6.1	17.0298
39		1010 580	5.9	19.3654
40		1030 As quench	9.5	10.9850

41	1030	540	8.5	12.6578
42	1030	580	8.1	14.2597
43	1050	As quench	9.7	10.9786
44	1050	540	9.0	16.5946
45	1050	580	8.9	17.9532

### 2.1 Analysis of Fracture Surface

The toughness ruptured surfaces show the different morphology for the specimens tempered two times at two distinct tempering temperatures. The results of H13 impact energy test clearly indicate that the toughness of material enhances while tempering two times after austenitizing. Quenching of H13 tool steel specimens were accomplished at austenitizing temperature (1010°C, 1030°C and 1050°C) after that tempering was performed two times above 540°C and 580°C. Austenitizing at 1010°C subsequent to tempering at 580°C two times provides high impact strength values against 1030°C and 1050°C. Thus, quenching at austenite temperature 1030°C indicate least toughness than that of quenching at 1010°C and 1050°C for the similar tempering temperature. Austenitizing temperature of 1010°C after tempering at 580°C resulted in enhances the toughness value of 17.63%. Tempering process was performed two times at 540°C which caused low impact strength values at all three austenitizing temperatures. During tempering performed at 540°C, the VC fine particle along with small Molybdenum content is spread all over the grain boundaries and matrix. Moreover, secondary martensite produced as existed retained austenite changed which effect the impact toughness and elastic properties of the tool steel.



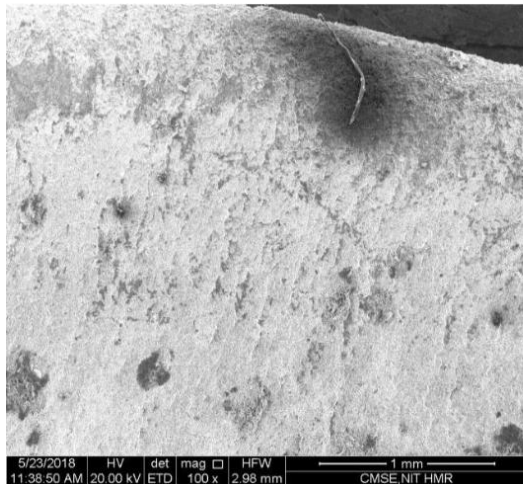
(a) Tempered at 580°C, twice.

(b) Tempered at 540°C, twice.

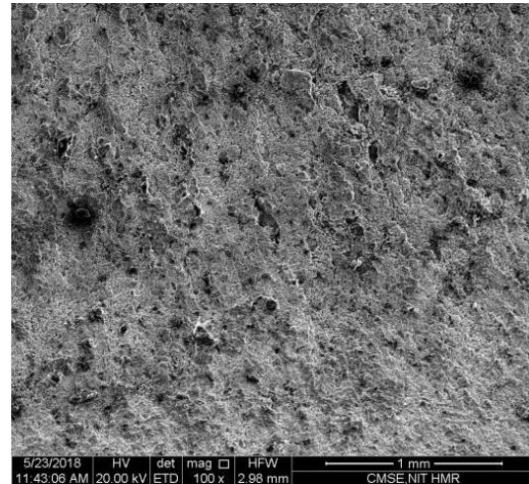
Figure 2. Austenitized H13 tool steel at 1010°C.

Investigation shows, the rupture surface tempered at 580°C has different rupture structure while examine at room temperature. The surface fractured during impact testing has higher value of impact energy at 1010°C austenitizing and raised lips on the rupture surface Figure 2. (left) taken by SEM exhibit this phenomenon. The H13 steel has relatively sound elastic property and impact toughness of this kind of ruptured surface. The material heated to 1010°C and tempered two times at 580°C after cooled by air furnace, and toughness value (19.61J) measured by Izod Impact tester support of above statement. The transgranular quasi-cleavage is major fracture method shown on these samples. It is clearly shown in fractography image that a segment of the fracture surface was inter-granular in nature which expose that there is a fall in transgranular quasi-cleavage element and a rise in the inter-granular element if austenitizing temperature rises from 1010°C to 1050°C. This fashion of rising inter-granular fracture along with rising austenitizing temperature is to occur likely, on the basis of the examination of the Quenched and tempered micro-structure of the martensitic materials. Also, more secondary micro-cracking could easily be seen in such fractograph. Figure 2. shows fractography image which show the difference between samples that were on automatization at temperature 1010°C but one is twice tempered at 580°C while other is twice tempered at 540°C. The micrograph of the specimen which is tempered two times at 580°C sample displays a mesh like micro-constituent with cleavage facets. If tempering is done two times at 580°C it results into a considerable plastic deformation throughout the fracture process. It could be easily seen that existence of the raising lips and rough structure of the rupture surface enhance impact strength by 17%. Such type of structure over rupture surface specifies good toughness

and ductility of the material. Same behavior is shown in the figure 3. and figure 4. below, when comparison is done on low magnification. As discussed above, it could be analyzed that the resistance of impact strength of tool steel is affected by variety of structural and physical constraints, for example hardness, size of grain and number of phases present in volume fraction etc. But the major constraints which affected by austenitizing temperature are hardness, size of grain, number of phases present in volume fraction type and quantity of several change in microstructure. Usually, fracture resistance has inverse relation to grain size as well as hardness. If Austenitizing temperature is greater than 1010°C, it leads to coarsening of the austenitized grain distribution, increase in the carbide's separation, increase in the tempered hardness ability and diminished Izod impact toughness.

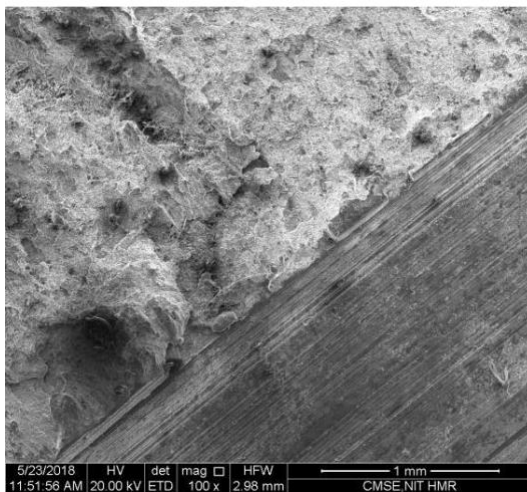


(a) Tempered at 580°C, twice.

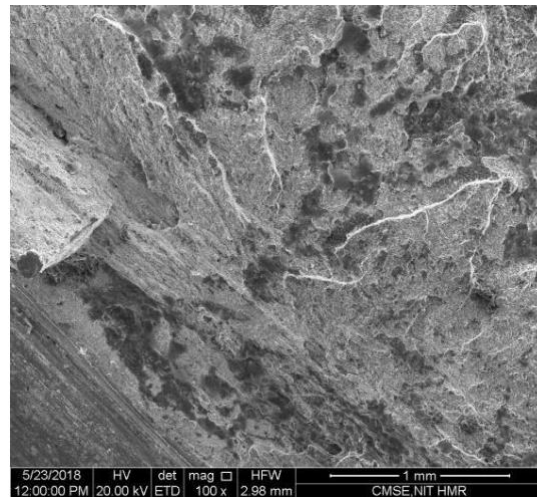


(b) Tempered at 540°C, twice.

Figure 3: Austenitized H13 tool steel at 1030°C.



(a) Tempered at 580°C, twice.



(b) Tempered at 540°C, twice.

Figure 4: Austenitized H13 tool steel at 1050°C.

**2.2 Grain structure analysis**

The impact of austenitizing temperature on the size of grain was studied and experimental results are presented in the figure 5. shown below. It can be analyzed from these images that, if the austenitizing temperature of H13 steel increases, the grain size will also increase.

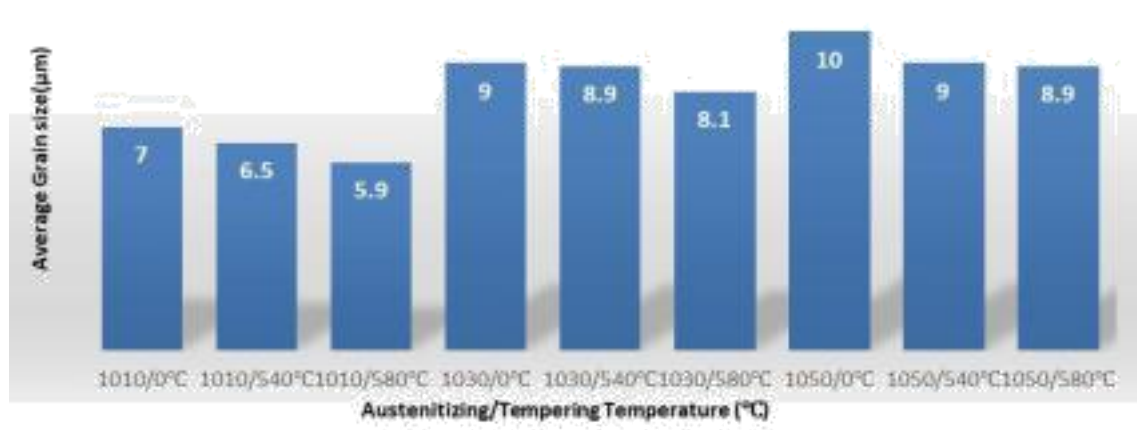


Figure 5: The effect of austenitizing and tempering temperature on grain size of H13 tool steel.

Figure 5. depicts the austenite grain size of specimen which is quenched at 1010°C, 1030°C and 1050°C. Tiny and uniform grain size are obtained at 1010°C and 1030°C but at 1050°C coarse and irregular grains grow. It can analyzed that the grain size at austenitic temperature grows gradually if there is a rise in quenching temperature. The grain size at austenitic temperature grows suddenly after the temperature rises to 1050°C. At 1030°C, a lot of uneven, rough and tiny grains are formed. This is because holding time is not sufficient to grow tiny grain and to achieve this holding time should be sufficient. At 1050°C coarse grains are obtained by H13 Tool steel, if the holding time is extended during austenitizing.

**2.3 Prediction Method**

**2.3.1 Artificial Neural Networking**

For determining the finest network structure of ANN prediction model, five criterions are considered. Similarities of line pattern, regression value (R), and MSE are the first three criterions. The residual error and prediction accuracy are the rest two. First criteria is the consideration of the line pattern data between ANN network toughness, grain size outputs  $\hat{G}$ , toughness and grain size targets G. Three structures with minimum value of MSE are drawn to get clearer graphs which are 2-5-2, 2-7-2 and 2-14-2. Hence, these two lines are represented over same graph. If there is a similarity in the two lines of graph, then it can be assumed that there is an accurate learning process. It also indicates that network outputs and target are in a good agreement. Second criteria is the consideration of the minimum value for the absolute average. Error value of MSE can also be calculated for each network structure, for justifying that the network structure gives finest and accurate prediction for grain size value. The objective is to minimize the absolute average, in order to justify the high accuracy predicting ability of model, when MSE approach to zero.

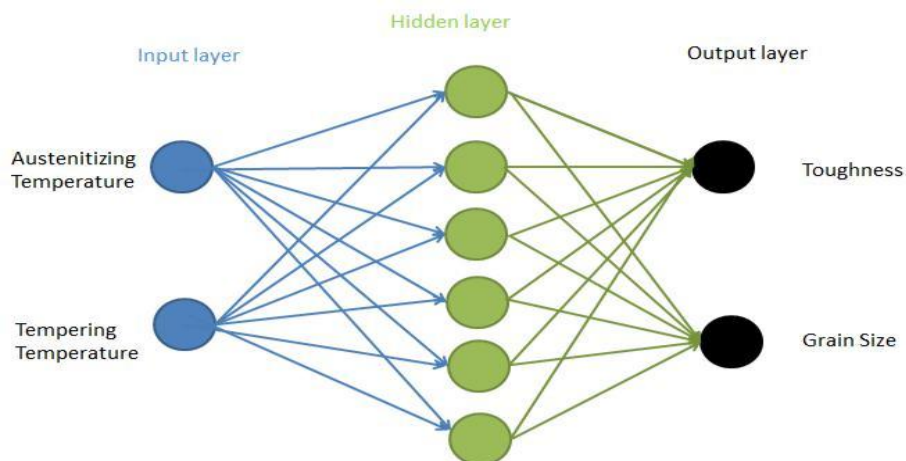


Figure 6.: Basic structure of ANN prediction model.

### 2.3.2 Prediction and Error result for architecture 2-7-2

The best criteria are the contemplation of regression value (R), refer to Fig7. which is representing the 2-7-2 ANN structure. In every plot, output = target is represented by the dashed line. Solid line represents the best fit linear regression line between target and output. The R indicates the relation between target and output. Greater R represents perfect result. If  $R = 1$ , It indicates that there is a linear relationship between output and target. However, for smaller R value, there is no linear relation between output and target. The training data in Fig 7 represents a good fit. The R value present in the validation and test also has a good fit, (greater than 0.99). The scatter plot shows that the certain data points have poor fit. The scattered data investigates various data points and is utilized to find out that weather it represents extrapolation or not. If yes, then it shall be included for training set, and supplementary data shall be taken for testing set. As experimental data contains less than 50 samples, Figure 7. represents that the R value for all datasets in 2-7-2 structure is greater than 0.99.

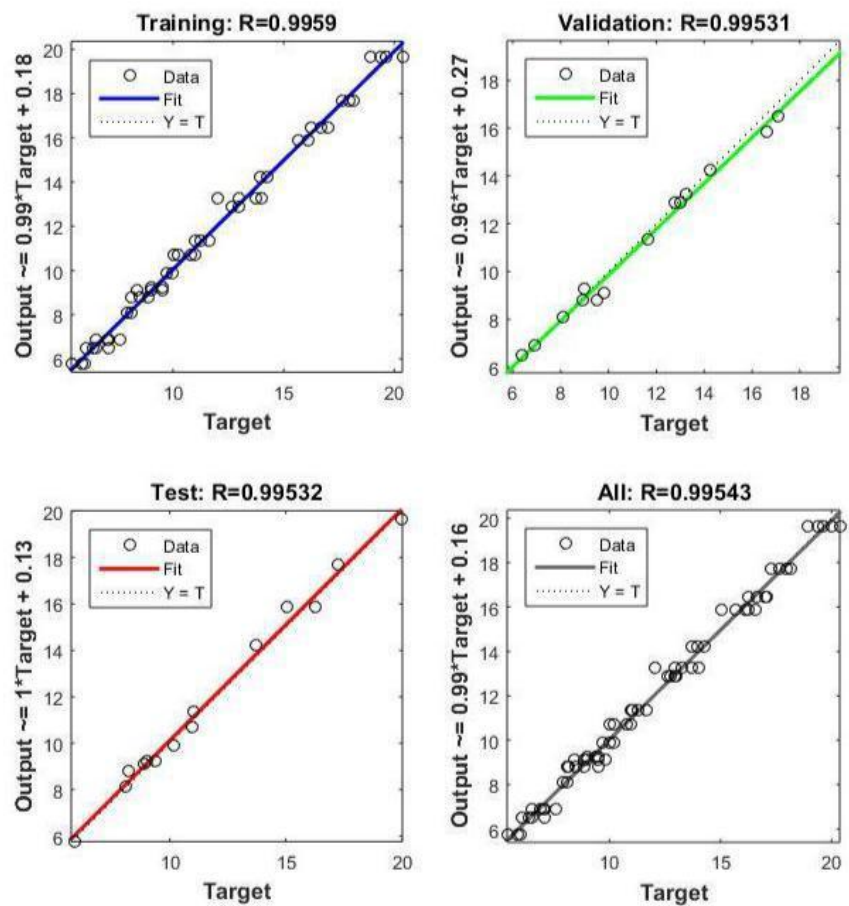


Figure 7.: ANN training regression for 2-7-2 structure.

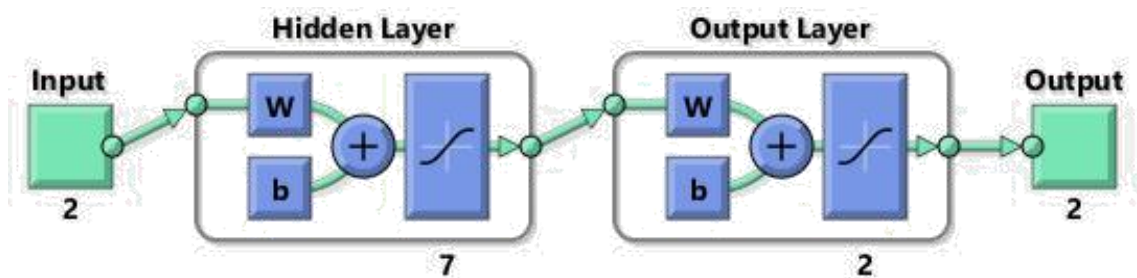


Figure 8.: Architecture 2-7-2 of ANN model.

Fig.8. shows graphical representation of the pattern of the data between the ANN (grain size and toughness) target data and ANN output data in Table 3.. From this we can analyze that the three network structures give same line pattern between ANN targets  $G$  and ANN outputs  $\hat{G}$  which are in 2-5-2, 2-7-2 and 2-14-2. The absolute value of toughness, grain size and the predicted values of ANN structure in training phase is



given in Table 3. By studying the absolute average value of MSE, it can be analyzed that the 2-7-2 network structure of the H13 tool steel gives the lowest absolute MSE average value which is 0.0001 for the best potential model.

Table 3 Prediction output and error value for 2-7-2 structure ANN.

Sr.No.	Austenitizing Temp. (°C)	Tempering Temp. (°C)	Grain size (µm)	Toughness (J)	Predicted Grain size (µm)	Predicted Toughness (J)	Error in Grain size	Error in Toughness
1	1010	As quench	7	13.7293	6.8860	13.2616	0.1140	0.4677
2	1010	540	6.5	16.6713	6.5075	16.4664	-0.0075	0.2049
3	1010	580	5.9	19.6133	5.7610	19.6602	0.1390	-0.0469
4	1030	As quench	9	11.2776	9.1181	11.3566	-0.1181	-0.0790
5	1030	540	8.9	12.7486	8.7901	12.9119	0.1099	-0.1633
6	1030	580	8.1	13.7293	8.1075	14.2425	-0.0075	-0.5132
7	1050	As quench	10.0	10.7873	9.8944	10.6870	0.1056	0.1003
8	1050	540	9.0	15.6906	9.2537	15.8634	-0.2537	-0.1728
9	1050	580	8.9	17.6520	8.7879	17.6914	0.1121	-0.0394
10	1010	As quench	7.1	14.0254	6.8860	13.2616	0.2140	0.7638
11	1010	540	6.4	16.2544	6.5075	16.4664	-0.1075	-0.2120
12	1010	580	6.0	18.9532	5.7610	19.6602	0.2390	-0.7070
13	1030	As quench	8.9	11.0154	9.1181	11.3566	-0.2181	-0.3412
14	1030	540	8.5	12.9802	8.7901	12.9119	-0.2901	0.0683
15	1030	580	8.1	14.2546	8.1075	14.2425	-0.0075	0.0121
16	1050	As quench	10.0	10.2258	9.8944	10.6870	0.1056	-0.4612
17	1050	540	9.5	16.1249	9.2537	15.8634	0.2463	0.2615
18	1050	580	8.5	18.1845	8.7879	17.6914	-0.2879	0.4931
19	1010	As quench	7.6	12.9562	6.8860	13.2616	0.7140	-0.3054
20	1010	540	7.1	16.2596	6.5075	16.4664	0.5925	-0.2068
21	1010	580	5.9	20.0159	5.7610	19.6602	0.1390	0.3557
22	1030	As quench	9.8	11.6542	1181	11.3566	0.6819	0.2976
23	1030	540	9.5	13.0115	8.7901	12.9119	0.7099	0.0996
24	1030	580	8.1	13.9543	8.1075	14.2425	-0.0075	-0.2882
25	1050	As quench	10.2	10.9857	9.8944	10.6870	0.3056	0.2987
26	1050	540	9.4	15.0254	9.2537	15.8634	0.1463	-0.8380
27	1050	580	8.2	17.2654	8.7879	17.6914	-0.5879	-0.4260
28	1010	As quench	6.9	13.2564	6.8860	13.2616	0.0140	-0.0052
29	1010	540	6.4	17.0659	6.5075	16.4664	-0.1075	0.5995
30	1010	580	5.4	20.3654	5.7610	19.6602	-0.3610	0.7052
31	1030	As quench	8.4	11.6598	9.1181	11.3566	-0.7181	0.3032
32	1030	540	8.1	12.9543	8.7901	12.9119	-0.6901	0.0424
33	1030	580	7.9	14.2546	8.1075	14.2425	-0.2075	0.0121
34	1050	As quench	9.7	10.0264	9.8944	10.6870	-0.1944	-0.6606
35	1050	540	9.0	16.2541	9.2537	15.8634	-0.2537	0.3907
36	1050	580	8.9	17.9542	8.7879	17.6914	0.1121	0.2628
37	1010	As quench	6.5	12.0254	6.8860	13.2616	-0.3860	-1.2362
38	1010	540	6.1	17.0298	6.5075	16.4664	-0.4075	0.5635
39	1010	580	5.9	19.3654	5.7610	19.6602	0.1390	-0.2948
40	1030	As quench	9.5	10.9850	9.1181	11.3566	0.3819	-0.3716
41	1030	540	8.5	12.6578	8.7901	12.9119	-0.2901	-0.2541
42	1030	580	8.1	14.2597	8.1075	14.2425	-0.0075	0.0172
43	1050	As quench	9.7	10.9786	9.8944	10.6870	-0.1944	0.2916
44	1050	540	9.0	16.5946	9.2537	15.8634	-0.2537	0.7312
45	1050	580	8.9	17.9532	8.7879	17.6914	0.1121	0.2618

### 2.3.3 Validation of ANN model accuracy

ANN model can be validated to be accurate on the basis of similarities of line pattern, and regression value (R) In order to have the right accuracy percentage; residual error and prediction accuracy are calculated in the contemplation of this percentage. To measure difference between actual and predicted data, residual error is used. It is a simple performance measure which is utilized for various studies. Prediction accuracy is also an important performance measure to see predicting accuracy of model while predicting output performance when input parameters are changed.

Table 4 MSE and R-value of toughness and grain size predicted values of ANN models.

Sr. No.	Architecture (Input-Hidden-Output)	Performance	
		MSE	R-Value
1	2-1-2	0.4	
2	2-2-2	0.6	0.86656
3	2-3-2	0.008	0.90645
4	2-4-2	0.3	0.89384
5	2-5-2	0.01	0.92368
6	2-6-2	0.1	0.95787
7	2-7-2	0.001	0.99543
8	2-8-2	0.9	0.98999
9	2-9-2	0.5	0.95359
10	2-10-2	0.65	0.94987
11	2-11-2	0.8	0.93699
12	2-12-2	0.08	0.84999
13	2-13-2	0.69	0.90879
14	2-14-2	0.002	0.91999
15	2-15-2	0.7	0.91987

Error of residual (e) and prediction accuracy (A) are calculated by using the following Equation

$$e = \frac{R_p - R_a}{R_p}$$

Where  $R_p$  is predicted value and  $R_a$  is actual value.

$$A = \frac{1}{n} \sum_{i=1}^n \left( 1 - \frac{|R_p - R_a|}{R_p} \right) \times 100\%$$

Where n is the as number of experimental data,  $R_p$  is predicted value and  $R_a$  is actual value and 'A' is the prediction accuracy.

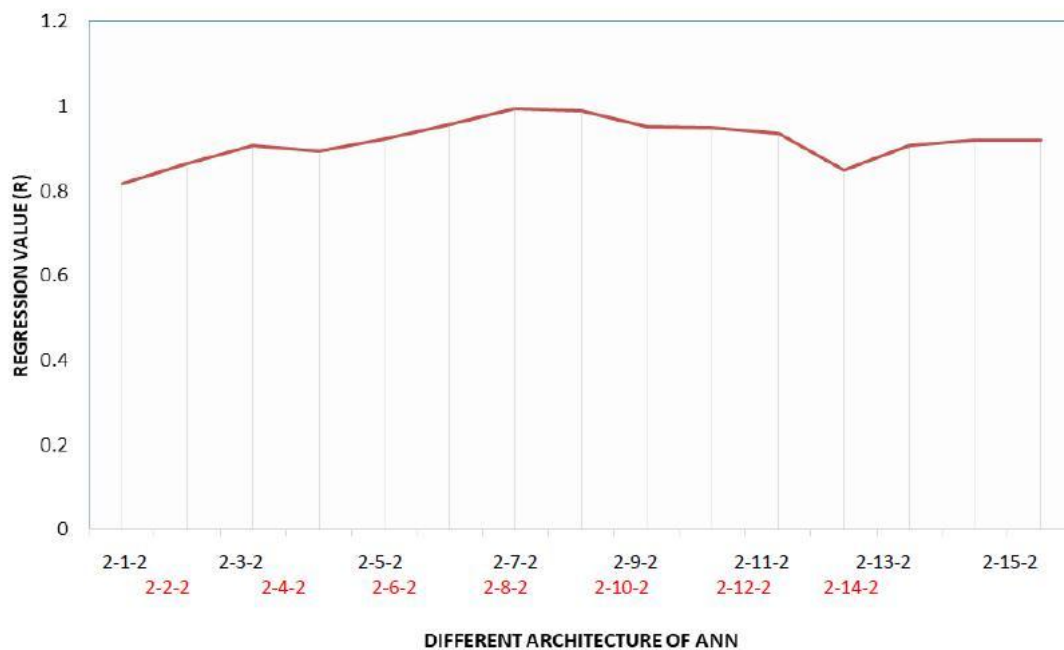


Figure 9: Different architecture used for prediction model and corresponding regression value.

From the fifteen architecture which are presented in the graph in Figure 9, the best three ANN structures were compared. In addition, this section presents a comparison and validation for the best three developed models by using actual experimental data. A structure of 2-5-2 and 2-14-2 has the largest values of maximum error percentage 7.03% and 13.01% respectively, while the average error is 7.63% for 2-5-2 and 8.01% for 2-14-2. This average percentage is considered as acceptable since the prediction accuracy is 92.37% and 91.99% for both structures respectively. However, the ANN model with 2-7-2 structure gives the best result with low maximum error 2.65% and high prediction accuracy value 97.35%. The work reported in this thesis divided into two major parts: The first part consists a concise literature review on various aspects of tool steel, such as mechanical properties, grain size and heat treatment processes. This chapter furnishes a foundation for variation of mechanical properties with respect to the austenitizing temperature. Apart from this, grain size variation of with respect to tool steel tempering followed by quenching (heat treatment process). The second part consists of other parameters which involve in the heat treatment processes like austenitizing temperature range, tempering time and number of time tempering is performed (once, twice and thrice). These parameters also have influence on the mechanical properties and grain size variation.

### III. Conclusion

The toughness and grain size have been measured at different austenitizing and tempering temperature. Based on these experiment results, following conclusions have been drawn:

- From the experiment values of toughness, it has been observed that the impact strength (toughness) of H13 steel decreases as the austenitizing temperature increases (range of 1010°C to 1050°C) without going through the tempering process. However, this increases as the austenitizing and tempering temperature increases.
- In austenite phase, heat treatment temperature is most important factor on the grain size determination. In this phase, influence of grain size is more significant on impact strength of H13 tool steel.
- For the same material, it is possible to obtain different grain size by relative variation of temperature at different heat treatment. The largest grain size gives lowest impact strength as compared to smaller one for H13 tool steel.
- For merely quenching, the impact energy increases as the grain size decreases and it will become minimum 10.7873J at 1050 °C as compared to 13.7293J at 1010 °C.

- Tempering process performed after quenching gives some adverse effect on toughness and grain size as in the quenching process. The grain size decreases as tempering temperature increases and maximum value of grain size 9  $\mu\text{m}$  has been observed at 540 °C.
- It has been observed from experimentations that there is no direct relation between toughness and grain size along with different heat treatment temperature.

## 5.2 Scope of future work

This study opens up a new avenue for the value-added utilization of industrial time as it predict the desirable properties required and leaves some wide scope for future work to explore many aspects such as heat treatment at small intervals of temperature, tempering time variation and tempering rate. Some recommendation for future research includes:

- Possible variation of austenitizing temperature at small interval to increase the experimental results.
- To investigate toughness and grain size at different tempering rate and tempering time. Study on the response of toughness and grain size on wear behaviors as wear is also responsible for failure of H13 tool die steel.
- Other different techniques used for prediction like genetic algorithm, machine learning etc. and comparisons with ANN.

## REFERENCES

- [1]. Qawabeha, U. F. Al. (2017). Effect of heat treatment on the mechanical properties, microhardness, and impact energy of H 13 Alloy steel. *International Journal of Scientific and Engineering Research*, 8(2), 100-104
- [2]. Qamar, S. Z., Sheikh, A. K., Arif, A. F. M., Pervez, T., & Siddiqui, R. A. (2007). Heat treatment of a hot-work die steel. *Archives of Materials Science and Engineering*, 28(8), 503-508.
- [3]. Liu, Yong, Jing-chuan Zhu, and Yong Cao. "Modeling effects of alloying elements and heat treatment parameters on mechanical properties of hot die steel with back-propagation artificial neural network." *Journal of Iron and Steel Research, International* 24.12 (2017): 1254-1260.
- [4]. Jian, Z. H. O. U., et al. "Microstructure and properties of hot working die steel H13MOD." *Journal of Iron and Steel Research, International* 20.9 (2013): 117-125.
- [5]. Guanghua, Yan, Huang Xinmin, Wang Yanqing, Qin Xingguo, Yang Ming, Chu Zuoming, and Jin Kang. "Effects of heat treatment on mechanical properties of h13 steel." *Metal Science and Heat Treatment* 52, no. 7-8 (2010): 393-395.
- [6]. Matarneh, Mohammad E. "The Effect of Austenitization Treatment Temperature on H-13 Tool Steel's Mechanical Properties." *International Journal of Mechanics and Applications* 6.4 (2016): 77-82.
- [7]. Yang, Hong-Seok, and H. K. D. H. Bhadeshia. "Austenite grain size and the martensite-start temperature." *Scripta materialia* 60.7 (2009): 493-495.
- [8]. Li, Jing-Yuan, Yu-Lai Chen, and Jian-Hua Huo. "Mechanism of improvement on strength and toughness of H13 die steel by nitrogen." *Materials Science and Engineering: A* 640 (2015): 16-23.
- [9]. Jilg, Andreas, and Thomas Seifert. "Temperature dependent cyclic mechanical properties of a hot work steel after time and temperature dependent softening." *Materials Science and Engineering: A* 721 (2018): 96-102.
- [10]. Medvedeva, Anna, Jens Bergström, Staffan Gunnarsson, and Jorgen Anderson. "High-temperature properties and micro structural stability of hot work tool steels." *Materials Science and Engineering: A* 523, no. 1-2 (2009): 39-46.
- [11]. Eser, A., C. Broeckmann, and C. Simsir. "Multi scale modeling of tempering of AISI H13 hot-work tool steel—Part 1: Prediction of microstructure evolution and coupling with mechanical properties." *Computational Materials Science* 113 (2016): 280-291.
- [12]. Asadi, P., et al. "Predicting the grain size and hardness of AZ91/SiC nano composite by artificial neural networks." *The International Journal of Advanced Manufacturing Technology* 63.9-12 (2012): 1095-1107
- [13]. Liu, G., Jia, L., Kong, B., Guan, K., & Zhang, H. (2017). Artificial neural network application to study quantitative relationship between silicide and fracture toughness of Nb-Si alloys. *Materials & Design*, 129, 210-218.
- [14]. Çol, M., H. M. Ertunç, and M. Yılmaz. "An artificial neural network model for toughness properties in micro alloyed steel in consideration of industrial production conditions." *Materials & design* 28, no. 2 (2007): 488-495.
- [15]. Esfahani, M. Botlani, M. R. Toroghinejad, and AR Key Yeganeh. "Modelling the yield strength of hot strip low carbon steels by artificial neural network." *Materials & Design* 30.9 (2009): 3653-3658.
- [16]. Okorafor, O. E. "Fracture toughness of M2 and H13 alloy tool steels." *Materials science and technology* 3.2 (1987): 118-124.
- [17]. Le Roux, Sabine, et al. "Image analysis of microscopic crack patterns thermal fatigue heat-checking of high temperature tool steels." *Micron* 44 (2013): 347-358. 46
- [18]. Souki, I., D. Delagnes, and P. Lours. "Influence of heat treatment on the fracture toughness and crack propagation in 5%Cr martensitic steel." *Procedia Engineering* 10 (2011): 631-637.
- [19]. Gevrey, Muriel, Ioannis Dimopoulos, and Sovan Lek. "Review and comparison of methods to study the contribution of variables in artificial neural network models." *Ecological modelling* 160.3 (2003): 249-264.
- [20]. Sjöstrom, Johnny, and Jens Bergstrom. "Thermal fatigue testing of chromium martensitic hot-work tool steel after different austenitizing treatments." *Journal of Materials Processing Technology* 153 (2004): 1089-1096.
- [21]. Li, Guobin, Xiangzhi Li, and Jianjun Wu. "Study of the thermal fatigue crack initial life of H13 and H21 steels." *Journal of materials processing technology* 74.1-3 (1998): 23-26.
- [22]. Podgornik, Bojan, et al. "Tool Steel Heat Treatment Optimization Using Neural Network Modeling." *Metallurgical and Materials Transactions A* 47.11 (2016): 5650-5659.
- [23]. ASTM E23-16b standard, Annual Book of ASTM Standards (2016).
- [24]. William D. Callister, Jr. *fundamentals of material science and engineering*. John Wiley & Sons, Inc.