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Technical Report

Developing a model for hardness prediction in water-quenched and tempered AISI 1045 steel through an artificial neural network

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ABSTRACT

The aim of the current study was to develop an artificial neural network (ANN) model to predict the hardness drop of the water-quenched and tempered AISI 1045 steel specimens, as a function of tempering temperature and time parameters. In the first stage, the effects of selected tempering parameters on the hardness drop value were investigated. In the second stage, a group of data, which have been obtained from experiments, was used for training of the ANN model. Likewise, another group of experimental data was utilized for the ANN model validation. Ultimately, maximum error of the ANN prediction was determined. The agreement between the predicted values of the ANN model with the experimental data was found to be reasonably good.

1. Introduction

It is difficult to determine the hardness of water-quenched steel after tempering heat treatment and it is one of the most important problems found during heat treatments of steels. Tempering is a process in which previously hardened steel is usually heated to a temperature below the lower critical temperature and cooled at a suitable rate to obtain specific values of hardness and mechanical properties [1]. All tempering treatments are carried out at temperatures below the lower critical temperature (A_1) of austenite formation.

Hardened steel can be tempered to reduce hardness and to increase toughness, as well. Plain carbon or low-alloy martensitic steels can be tempered in lower or higher temperature ranges, depending on the balance of properties required [2]. The effect of tempering is controlled by the tempering temperature and time [3]. The tempering temperature and time determine the hardness drop. During tempering, a decrease in hardness is usually accompanied by an increase in toughness [4]. The tempering treatment controls the final properties of the steels. This treatment after water-quenching treatment is used to obtain steel with desired properties [5]. For low to medium carbon steels, the tempering treatment establishes the hardness of the steel, and for tempered martensites, the hardness can be used to estimate tensile strength [6]. Wei et al. pointed out that the wear resistance was suggested to depend on hardness and the wear resistance was found to closely correlate with the tempering conditions and wear mechanism [7].

Mukherjee et al. presented a technique for calculating the hardness of the tempered martensitic rim as a function of chemical composition and non-isothermal tempering parameters [8]. Kamp et al. have investigated the effect of short time tempering of the order of few seconds to few minutes on the mechanical properties of two cold rolled and hot-dip galvanized dual-phase steels [9].

After performing the experiments, in the first stage, the effects of tempering temperature and time on hardness drop of water-quenched AISI 1045 steel were investigated. In the second stage, an artificial neural network (ANN) model was developed to predict the hardness drop of the water-quenched and tempered AISI 1045 steel specimens, as a function of tempering temperature and time parameters.

2. Methodology

2.1. Preparation of samples

The material used for the experiments was commercially produced cold-rolled annealed AISI 1045 steel. The specimens for the hardness test were cut from same batch of materials. Then they were turned and then ground on both ends by the surface grinder. Dimension of specimens are shown in Fig. 1. To avoid the problem of curvature and to produce flat surfaces with the smooth finish, grinding operation was performed on both ends of specimens.

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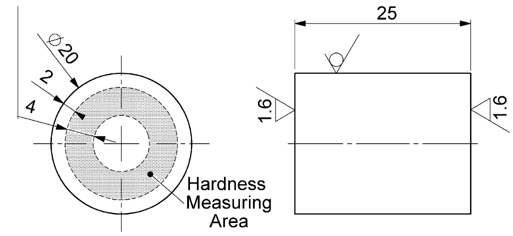

Fig. 1. Specimen drawing.

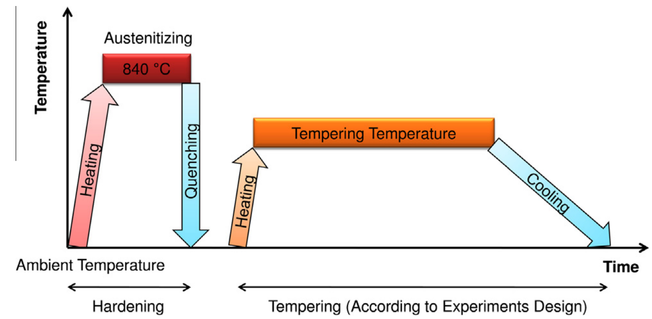

Fig. 2. Graphical illustration of experiments stages.

2.2. Configurations of experiments

The prior austenite grain size, carbon and alloy content of selected steel were assumed constant in this study. To reduce the error caused by these factors, the specimens were selected from the same batch of raw materials. The effects of the mentioned factors are beyond the scope of the current study.

The whole experiments have been divided in two stages. In the first stage of experiments, A full factorial design of experiment is conducted using tempering temperature factor with 3 levels (200, 350 and 500 °C) and tempering time factor with 6 levels (10, 20, 40, 60, 80 and 100 min) and as a result 18 sets of factorial experiments were created. In this paper, experiments which were carried out under the aforementioned configurations (18 sets) were named "Training Experiments". The configurations of Training Experiments are shown in the first and the second columns of Table 1. The results of these experiments were used for training of the ANN model.

2.3. Water-quench heat treatment

The specimens under investigation were heated above their upper critical (A_3) temperature (840 °C) in an electrical furnace for 15 min. Then the red-hot specimens quickly cooled down (quenched) through immersing in water at ambient temperature to acquire the martensite microstructure. This process is graphically illustrated in Fig. 2. Optical micrograph of water-quenched AISI 1045 (Ck45) sample steel (etched with nital 3%) is presented in Fig. 3 [10].

Numbering of each test was performed based on the levels of each parameter. These values dictate the level of each factor: conventionally, 1 for the lowest level, 2 for the second, 3 for the third, 4 for the fourth, 5 for fifth and 6 for sixth level. For example, in test T24, digit 2 indicates the second level of tempering temperature (350 °C); Digit 4 indicates the forth level of tempering time (60 min).

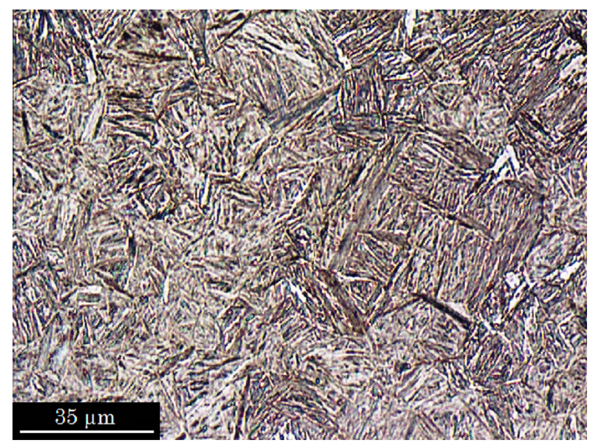

Fig. 3. Optical micrograph of water-quenched AISI 1045 sample steel (etched with nital 3%).

As aforementioned, the results of Training Experiments were used for training of the ANN model. Thus, there should be other data for testing the goodness of the created ANN model. In the second part of experiments, other experiments with random configu-

Table 1
Tempering condition and hardness of each specimen after water-quenching and tempering treatments for Training Experiments.

Test no.	1. Tempering temperature (°C)	2. Tempering time (min)	3. Hardness after water-quenching (HRC)	4. Hardness after tempering (HRC)	5. Hardness drop (HRC)	6. Predicted hardness drop by ANN (HRC)
T11	200	10	55.5	52.5	3.0	3.23
T12		20	55.0	52.0	3.0	3.70
T13		40	54.4	50.3	4.1	5.04
T14		60	55.6	50.3	5.3	6.12
T15		80	55.4	49.5	5.9	6.52
T16		100	55.9	50.5	5.4	6.59
T21	350	10	56.5	48.5	8.0	8.63
T22		20	55.0	45.0	10.0	10.72
T23		40	56.5	43.5	13.0	13.49
T24		60	55.0	40.7	14.3	14.50
T25		80	54.5	41.5	13.0	14.06
T26		100	56.0	42.0	14.0	13.83
T31	500	10	56.0	35.5	20.5	20.57
T32		20	56.0	35.0	21.0	22.29
T33		40	57.0	32.5	24.5	25.37
T34		60	57.0	29.5	27.5	27.00
T35		80	57.0	30.0	27.0	27.01
T36		100	56.5	30.0	26.5	25.78