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Microstructural prediction through artificial neural network (ANN) for development of transformation induced plasticity (TRIP) aided steel

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ABSTRACT

The prediction of the amount of retained austenite as a function of chemical composition and heat treatment is important for achieving the desired properties in TRIP (Transformation Induced Plasticity) aided steel. In the present work, three experimental steels (CMnSiAlP, CMnSiAlNb and CMnSiNb) made in vacuum induction furnace were suitably heat treated in hot dip processing simulator (HDPS) to produce multiphase TRIP microstructure. The process parameters were determined with the aid of multilayered perception (MLP) based artificial neural network (ANN) models in combination with the results of the study of the transformation behaviour. Amount of retained austenite in microstructure measured by optical microscopy and X-ray diffraction technique had shown a good agreement with that predicted through the afore mentioned model. All three alloys were found to have an excellent strength–ductility balance and significantly good strain hardening exponent (n) value. Among the three grades, CMnSiAlNb grade was observed to have a better combination of properties in terms of high strength and ductility.

1. Introduction

In recent years, TRIP aided steel has received prominence in the automobile industry for designing light-weight vehicles with adequate passenger safety in terms of crash worthiness. Its microstructure typically consists of ferrite, bainite and retained austenite. TRIP effect emerges from transformation of metastable austenite to martensite during straining, offering an excellent combination of strength and formability.

The TRIP effect results in superior ductility at high strength levels [1] by dint of (i) composite strengthening through formation of martensite particles dispersed in the ferrite matrix and (ii) formation of dislocations around newly formed martensite regions as a result of the volumetric expansion during the austenite to martensite transformation [2,3]. This ultimately leads to high strain hardening rate and dynamic energy absorption capacity making the steel suitable for passive safety structural applications like bumper reinforcement, door impact beam, etc [4]. Since retained austenite is the most crucial component for TRIP effect, it is imperative to understand its correlation with chemical composition and process parameters. The conventional TRIP aided steel contains 0.15–0.20 wt% carbon, around 1.5 wt% silicon and 1.5 wt% manganese [5]. Silicon contributes significantly towards achieving higher amount of retained austenite [5]. However, it is desirable to control its presence to minimise its deleterious effect on surface quality and weldability [5–7]. Rationalisation of silicon through aluminium addition is one of the means [8] for overcoming this. However, aluminium has a weak solid solution strengthening effect compared with silicon and therefore addition of phosphorous or microalloying elements (especially niobium) is favoured for achieving the required strength level [1,2,5]. The amount of retained austenite depends to a great extent on the composition and heat treatment time and temperatures during intercritical annealing (IA) and isothermal bainitic transformation (IBT) treatment steps. Numerous experimental endeavours are still on for arriving at optimum combinations of process parameters and chemistry so that the right amount of retained austenite could be obtained for adequate TRIP effect. Therefore, for achieving the desired microstructure, it is important to understand the role of the alloying elements and process parameters (especially IA and IBT) individually and their interaction [5].

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Artificial neural network (ANN) has matured as an invaluable tool [9] for developing data-driven non-linear models. It captures complex relationships without the need to fix the mathematical form of the relationship at the outset. It is enhanced by a proper consideration of errors and uncertainties [10–15]. Artificial neural network has been applied for the prediction of retained austenite in TRIP aided steel [16].

Neural networks are non-linear models used for empirical regression and classification modelling. Due to their flexibility, these models can find out more complex relationships in data than conventional linear statistical models and at the same can avoid over fitting [17–19]. It is an empirical method and hence requires experimental data in order to discover the relationships. A neural network is 'trained' on a set of examples of input and output data. The outcome of training is a set of coefficients (called weights) and a specification of the functions which in combination with the weights relate the input to the output. The training process involves a search for the optimum non-linear relationship between the inputs and the outputs and is computer intensive. Once the network is trained, estimation of the outputs for any given set of inputs is rapid. The present work deals with optimisation of the process parameters for achieving the desired amount of retained austenite in three experimental steels with the help of ANN in order to propose an appropriate composition with improved coatability [20].

2. Selection of materials

The compositions of the steels selected for this work are shown in Table 1.

Reported results on TRIP-aided steel were critically analysed and various international standards e.g. DIN EN 10336 [21] presently merged with DIN EN 10346 [20] were considered to frame the compositions with an aim to achieve a combination of very high strength and high uniform elongation in low carbon-cold rolled and annealed TRIP-aided steel with enhanced wettability during hot dip galvanising and weldability [22]. The outcome of the work on development of CMnSiAlNb steel [8] was also examined by the authors. As already discussed, TRIP aided steels are given a two-stage heat treatment consisting of intercritical annealing and austempering to obtain the desired microstructure. The carbon content of the steel was restricted to 0.2 wt% to ensure good weldability [23]. The hot rolled strips were air cooled to room temperature; the microstructure of the hot rolled material consisted of ferrite and pearlite. This was the starting material for subsequent cold rolling and two-stage heat treatment.

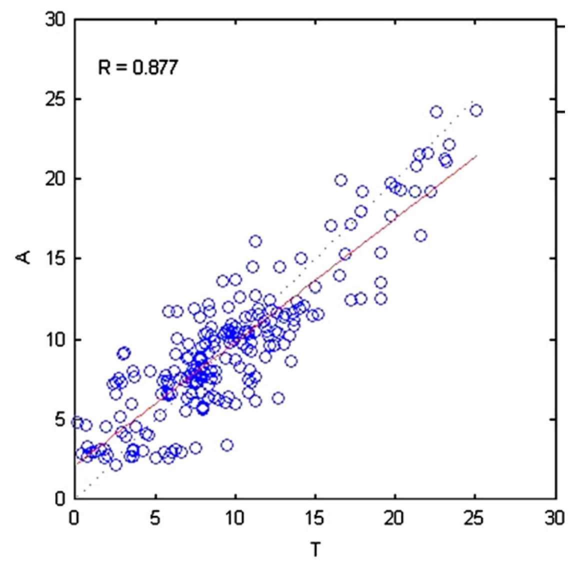

Fig. 1. Performance of ANN model in the form of scatter plot for predicted percentage of retained austenite (*T*) vs. actual percentage of retained austenite (*A*).

Table 1
Steel composition (wt%).

Grade	C	Mn	S	P	Si	Al	Nb
Grade 1 CMnSiAlP	0.22	1.43	0.007	0.065	0.62	1.18	0.003
Grade 2 CMnSiAl Nb	0.21	1.58	0.008	0.017	0.66	1.30	0.032
Grade 3 CMnSiNb	0.20	1.36	0.015	0.015	1.69	0.009	0.035

Table 2
Data used for modeling.

Input variables	**Symbol used**	**Minimum**	**Maximum**	**Mean**	**Standard deviation**
Carbon	**C**	0.08	0.39	0.19	0.07
Silicon	**Si**	0.02	2.48	0.95	0.67
Manganese	**Mn**	0.83	2.55	1.49	0.31
Phosphorus	**P**	0	0.20	0.03	0.05
Aluminium	**Al**	0	1.90	0.31	0.59
Niobium	**Nb**	0	0.08	0.001	0.01
Chromium	**Cr**	0	0.44	0.02	0.07
Intercritical annealing temperature	**IA_Temp** (°C)	760	860	794.2	27.3
Intercritical annealing time	**IA_Time (s)**	52	1200	328.5	263.3
Isothermal Bainitic Transformation Temperature	**IBT_Temp** (°C)	300	600	420.6	39.6
Isothermal Bainitic Transformation Time	**IBT_Time (s)**	1	3500	427.8	568.1
Fraction of retained austenite	**fa**	0.17	25.1	9.68	5.23

Table 3
Technical/architectural information.

Nodes in input layer	Nodes in output layer	Nodes in hidden layer	Input to hidden layer transfer function	Hidden layer to output transfer function	Output variable	*R* value	MSE value
11	1	15	Hyperbolic tangent	Linear	f_a (phase fraction, austenite)	0.877	0.033217