Intelligent Modelling and Optimisation of Metals Heat Treatment Process

Tawfeeq Al-Kanhal♥, *D.K. Suker*♦ *and M.F. Abbod*♥

♥*School of Engineering and Design*
Brunel University, West London, Uxbridge, UK. UB8 3PH

♦*Mechanical Engineering Department*
College Of Engineering, University of Umm Al-Qura, Makkah - Saudi Arabia

♥*Tawfeeq.Al-kanhal@Brunel.ac.uk*

Introduction

Heat treatment is a process used to alter the physical and mechanical properties of materials without changing the product shape by controlling heating and cooling rates. In the steel industry, determining the optimal heat treatment regime that is required to obtain the desired mechanical properties of the steel is considered as one of the hard and complex processes in the industry. This is because the search space is large and complicated. Therefore, it is important to develop a system that is capable of selecting the optimal heat treatment regime so the required metal properties can be achieved with the least energy consumption and the shortest time.

In this research experimental heat treatment data is used to develop a neuro-fuzzy (NF) system that models the materials properties such as the hardness and its depth. Based on this model, Particle Swarm Optimisation (PSO) is used to optimise the heat treatment process by selecting different heat treatment conditions. The selected conditions are evaluated so the best selection can be identified.

This work addresses the issues involved in developing a suitable methodology for developing an NF system and PSO for mechanical properties of the steel.

Methodology

In the field of artificial intelligence, neuro-fuzzy refers to combinations of artificial neural networks and fuzzy logic. An NF system is defined as fuzzy system which employs a self learning algorithm derived and inspired by neural network concept to achieve its fuzzy sets and fuzzy rules using processing data samples **Error! Reference source not found.** . The next step is to integrate the NF systems with PSO methodology [1] so that the system can predict the optimum heat treatment regime.

PSO is utilised to find the optimal heat treatment conditions which will provide the desired mechanical properties such as hardness and depth of hardness with the aid of the NF as the model used to predict the metal properties (Figure 1). The heat treatment data that is used to train the NF model is organised as input parameters (diameter, austenitic temperature, tempering temperature, induction speed, pressure, and sub-zero treatment) which the outputs are the hardness and its depth. The model was trained and tested using NF model which gave very good prediction accuracy. Accordingly, there are two objectives that need to be achieved, the hardness and its depth which lead to the need of a multi-objective optimisation algorithm. Two methods were used to evaluate both objectives: the first using Pareto Front function while the second method is based on a mean value of the normalised objectives.

Results

The PSO algorithm was set to a population size of 100, while the inertial cognitive and social constants are as follows: W_{min} = 0.4, W_{max} =0.9, $c1$ = 1.4, $c2$ = 1.4.

The NF system was tested using experimental data which proved to be able to give accurate predictions. Simulation results shown in Tables 1 and 2 based on the mean normalised objectives and the Pareto Front methods respectively show that the system was able to fine the desired properties by adjusting the heat treatment conditions.

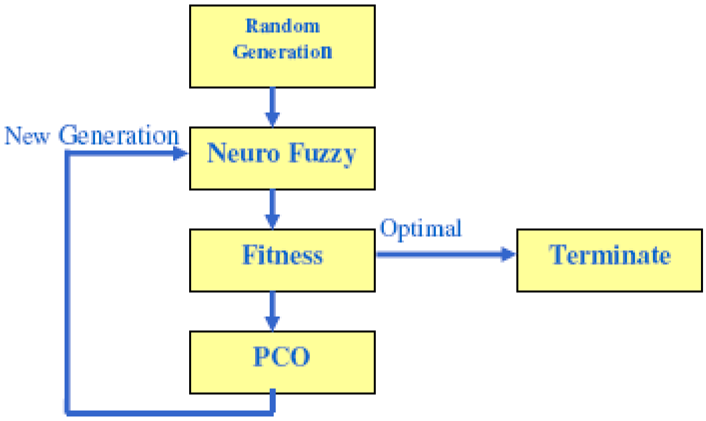

Figure 1. Block diagram of the system.

Table 1. Optimisation results of the NF and PSO using normalised objectives.

Diameter (mm)	Austenitic Temperature (°C)	Induction Speed (m/s)	Pressure (Bar)	Sub-zero treatment (°C)	Tempering Temperature (°C)	Hardness (MPa)	Depth of Hardness (mm)	Desired Hardness (MPa)	Desired Depth of Hardness (mm)
385	1012	0.52	26	-105	100	855.98	44.03	856	44
455	1002	0.54	30	0	102	876	24.81	876	25
455	1004	0.54	31	0	107	862	23.98	862	24
385	1020	0.49	26	-139	105	851.99	47.99	852	48
546	953	0.74	15	0	150	849	41.76	849	42
546	937	0.68	34	-5	107	875	28.98	875	29
380	1008	0.51	28	-3	105	932	30.58	932	34
455	1013	0.51	28	-5	103	883	28.39	883	34
455	1008	0.53	29	0	105	856	25.50	856	28

Table 2. Optimisation results of the NF and PSO using Pareto-Front.

Diameter (mm)	Austenitic Temperature (°C)	Induction Speed (m/s)	Pressure (Bar)	Sub-zero treatment (°C)	Tempering Temperatur e (°C)	Hardness (MPa)	Depth of Hardness (mm)	Desired Hardness (MPa)	Desired Depth of Hardness (mm)
385	1025	0.45	19	0	100	855.84	44.47	856	44
455	976	0.53	30	-10	100	875.99	25.01	876	25
455	930	0.4	28	-18	100	862.01	24.01	862	24
385	1025	0.4	15	0	100	851.57	48.05	852	48
546	930	0.650	15	0	150	849.15	41.99	849	42
546	940	0.8	27	0	108	875.39	29.06	875	29
380	991	0.4	25	0	100	930.65	35.03	932	34
455	1009	0.4	25	0	100	885.00	33.45	883	34
455	978	0.42	26	0	100	855.91	28.07	856	28

Conclusion

The NF system and PSO have has been developed successfully and working effectively. This system has been able to determine the heat treatment regime and the required to obtain the desired mechanical properties of the steel which considered as helpful tool in industry.

References

[1] J.-S. Roger Jang, "ANFIS: Adaptive-Network-Based Fuzzy Inference Systems", IEEE Transactions on Systems, Man, and Cybernetics, Vol. 23, No. 03, pp 665-685, May 1993.

[2] J. Kennedy, and R. Eberhart, "Particle Swarm Optimization", Proc. IEEE Int'l. Conf. on Neural Networks, Perth, Australia, pp.1942-1948, November 1995.