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Optimization of Strength and Toughness for Hot-Forged Bainitic Medium Carbon Steel Using RSM

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ABSTRACT

This work presents the experimental results and statistical analysis of the strength and toughness for an isothermally heat-treated medium carbon steel of composition 0.415% C, 1.67% Si, 1.22% Mn, 0.97% Cr, and 0.29% Mo, with varying Al contents in the range (0.00-1.16%) by response surface methodology (RSM). The effect of aluminum content, as well as the isothermal treatment at 300°C for 24–120 hrs in terms of varying the holding time is studied and correlated with the mechanical properties of the steel and state of art findings. Design of experiments and ANOVA were implemented for statistical analysis using Design Expert software. The results show the predicted range of combinations of Al wt.% and holding time that yields the highest values of the responses (Yield strength, ultimate tensile strength, impact energy and hardness). Moreover, the regression equations for each response and the optimum values of the controllable factors to maximizes the responses values are introduced.

Keywords: Medium carbon steel; Isothermal transformation; Bainitic steel.

INTRODUCTION

The combination between strength and toughness of medium carbon steels is a significant objective for steel manufacturers.[1-4] This objective is achieved via a number of heat treatment routes including quenching and tempering, thermomechanical treatment, bainite forming, etc., among which bainite transformation has yielded significant results. Novel heat treatment routes for enhancing the mechanical properties of medium carbon steel called quenching and partitioning treatment[5-6] have been also investigated. Those novel heat treatment routes resulted a triplex microstructure of bainite, martensite and retained austenite in medium carbon steels with an optimized combination of strength (1617–1715 MPa), elongation (13.7–19.2%), and maximum impact toughness (78–103 J).[7-8]

Bainitic microstructure obtained through heat treatment at low temperature ranges were shown to possess optimized mechanical properties for medium/low carbon steels.[9-13] The earlier work has contributed to the current understanding of the role of high carbon concentration in reducing the minimum transformation temperature for bainite formation. The evolution and transformation of the bainitic structures was thoroughly investigated in literature.[9-13] Single and multi-step isothermal heat treatment cycles were tailored to eliminate the thermally and mechanically less stable austenite blocks in favour of bainitic transformation to nanoscale bainitic–ferrite plates and thin film-like austenite, showing superior mechanical properties.[14,15] Several studies investigated the effect of controlling the isothermal heat treatment parameters in terms of temperature and holding time[9,11,16] on the structure and the mechanical properties of the steel. Isothermal holding time is reported to be an important parameter, in addition to the holding temperature, in controlling the bainite volume fraction; as finer bainitic structures are obtained at lower temperatures as close as possible to the martensitic formation temperatures and the bainite volume fraction increases when the transformation isothermal holding time increases.[9,11,16]

Though modifying the steel alloy design is an important area for study,[17-22] the available literature does not cover it extensively. Generally, manganese and chromium are added for hardenability, molybdenum to prevent temper embrittlement due to

