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ORIGINAL ARTICLE

Optimization of gas carburizing treatment parameters of low carbon steel using Taguchi and grey relational analysis (TA-GRA)

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Abstract
This work aims to optimize the micro-hardness (H), thickness of the hardened layer (THL), carbon contents (%C) and surface roughness (Ra) of XC10 steel using a gas carburizing thermochemical treatment. The combination of Taguchi and grey relational analysis (TA-GRA) was applied with 9 experiments on the basis of L9 orthogonal design using the following factors: carbon flow rate (0.9%, 1% and 1.2%), temperature (900°, 920° and 940°) and holding time (4 h, 5 h and 6 h). A statistical analysis of the results was carried out on the basis of the *S/N* ratio and an ANOVA to identify the most significant parameters affecting the experimental responses. A desirability function approach was established to find the optimal factors to maximize H, THL and %C and minimize Ra. The gas carburizing treatment has shown a strong increase in the micro-hardness with about 140%, the thickness of the hardened layer with more than 1400 µm, carbon content 775% and good decrease in the surface roughness (Ra) with 140%.

Keywords Gas carburizing of steel · Surface roughness · Thickness of the hardened layer · Micro-hardness · TA-GRA · Desirability function

1 Introduction

Low carbon steels have been commonly used because they guarantee high performances such as good plasticity, toughness and wear resistance. Moreover, it is one of the most used in the national economy, and it is often used after heat or thermochemical treatment [1–3]. Some carbon steel parts (shafts, gears, connecting rods and machine tool parts, etc.) must have enough toughness to resist fatigue (resistance to dynamic loads), tribological properties (resistance to friction and wear) and corrosion (resistance to chemical attack) [4–7]. The surface hardening was an accepted technology around the world because of its cost and its characteristics [8].

Up to date, different methods of cementing with different principles have been studied to produce activated carbon, such as gas carburizing [9], plasma carburizing [10, 11], vacuum carburizing [1], plasma electrolytic carburizing [12], electron beam carburizing [13] and laser carburizing [14].

In gas carburizing, the surface of low carbon steel can be enriched with carbon up to 1% (weight) [15, 16]. The increase of the surface layer with the carbon content shows the transformation of austenite into martensite and finally formation of cementite (Fe_3C) [17–19]. Furthermore, there are a lot of transformations in the core of the samples; ferrite and pearlite (initial phase) are transformed into retained austenite and bainite (after treatment phase) [20–22]. After thermochemical case hardening, if the steels are cooled in the furnace, an accumulation of thick and hard layers of cementite will occur within the grain boundaries, so case hardening without quenching and tempering has several drawbacks [21, 23, 24].

The case hardening treatment was carried out between 880 and 950 °C to improve the surface hardness of the steel parts, resulting in case hardened layers of up to 20–25% [25, 26]. The researchers have shown that the outer layer of the steel is characterized by a higher hardness when there is a similar increase in

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