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Research Paper

Thermal and metallurgical characteristics of surface modification of AISI 8620 steel produced by TIG arcing process

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ABSTRACT

The influence of TIG arcing process for surface modification of AISI 8620 steel at varying arcing current and heat input was studied in this work. Weld isotherm, thermal cycle and cooling rate of the modified region was estimated by analytical modeling and experimentally validated. Thermal characteristics of the modified zone were correlated with their respective microstructure and hardness. Cooling rate as a function of area of fusion influences the microstructure and hardness of the modified region. The multi-pass TIGA process for larger area of modification on substrate was applied using optimum arcing parameters for the best possible result found in a single pass. The effect of multiple thermal cycles on phase transformation and tempering of modified matrix were studied by microstructure analysis and mapping of its influence on the hardness distribution in the matrix. Residual stresses in the modified matrix created by single pass TIG arcing were measured by standard central drill hole technique. The surface modification of AISI 8620 steel by TIGA process shows the appreciable martensitic phase transformation in the matrix that enhances the hardness of the modified zone as well as introduces compressive residual stresses in it.

1. Introduction

AISI 8620 steel is used in various applications of automobile, aerospace and earth exploration industries as a bearing component. In the bearing application the materials are required to have high surface hardness along with good core toughness. As reported by Erdogan and Tekeli (2002), AISI 8620 steel is largely used as bearing and gear application after employing surface hardening treatment on it mostly by carburizing process. However, this process has certain disadvantages as it produces shallow (≤1.5 mm) case depth and appreciable environmental pollution. Davis (2002) has described that carburization process is highly labor intensive, takes long processing time and also requires attention to safety and fire prevention.

Lampman (1991) has described that besides carburizing there are several other conventional surface modification processes like thermal diffusion process, applied energy methods, coating and thermal spraying methods. Surface modification of materials is also produced by laser and electron beam technique where the high energy concentrated beam is used to produce sharp thermal gradients, which allow rapid heating and cooling cycle resulting desired phase transformation in the surface. High energy concentrated beam processes are the well established technique for surface modification of steel, but these techniques also have certain disadvantages like shallow case depth (<1 mm), high operation cost, skilled worker requirement and non versatile at sites as reported by Tusek and Suban (1999). In these respects Ghosh and Kumar (2015) have found that autogenous TIG arcing (without filler) process is very effective for versatile application in surface modification of steel with certain primary advantages. The use of TIGA is considered in combination of producing deep case depth at low processing time with less environmental pollution executed under a low overhead and operating cost.

Davis and King (1993) have described that the physical and mechanical properties of modified zone are influenced by its cooling rate, which is directed by the effectiveness of the sink depending on heat distribution in different zones of the modified substrate. Çalik (2009) has reported that increase in cooling rate (CR) and carbon content in steel enhances hardness that is owed to solid solution hardening and phase transformation. Thus geometry of the fused zone controls its thermal cycle and affects the solidification behavior. Hence, an estimation of thermal behavior, defined by the heat distribution at different zones governing the cooling rate of the fused zone (FZ) and heat affected zone (HAZ), prior to TIGA process may be very effective in optimizing the process and procedure. The arcing process control is governed by appropriate manipulation

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Table 1
Typical requirements for bearing application of AISI 8620 steel.

Application	Minimum Depth of Surface Modification	Case Hardness	Core Hardness	Hardening Processes
Rolling bearing rings (Races)	10% of Thickness of bearing rings	420–600 Hv	250–350 Hv	Diffusion Processes Advance energy methods Flame/induction hardening

of arcing parameters and their remarkable effect on weld thermal cycle. So it is imperative to select the proper arcing parameters to obtain desired metallurgical and mechanical characteristics of surface modification by fusion.

Due to high heating and cooling rate, steeper thermal gradient and phase transformation in high energy concentrated beam processes, residual stresses is induced in the modified region. These residual stresses may be tensile or compressive in nature depending upon the process and parameters used. Jeffrey D. Thiele et al. (2000) have pointed out that the influence of residual stresses on the material can be either beneficial or detrimental depending on the magnitude and nature of the residual stresses. Taljat et al. (1998) has described that tensile residual stress over the surface, promotes brittle fracture, reduces the fatigue life, and encourage stress corrosion cracking. Lampman (1991) has described that the compressive residual stress is beneficial for inducing high wear resistance, increased fatigue life and improved corrosion resistance.

In this work an effort is made to study the effective use of autogenous TIG arcing (TIGA) process for surface modification of AISI 8620 steel with reference to the requirements of its use in bearing applications as shown in Table 1. The effect of thermal behavior on phase transformation in the fusion and HAZ at different arcing parameters is considered in this study. Fusion zone geometry and cooling rate is estimated by the three dimensional double ellipsoidal heat source model proposed by Nguyen et al. (1999) and validated with experimental work. To analyze the effectiveness of the TIGA process for industrial application, multi-pass arcing process is employed to modify larger surface area of the substrate. The residual stress analysis is also carried out at the fusion zone of the single pass TIGA process.

2. Analytical estimation of thermal characteristics

Firstly Rosenthal (1941) found the solution for the temperature distribution in a position away from the concentrated heat source in a heat conductive system while considering it as a point heat source. But, this consideration was not found effective in estimating the thermal characteristics of the weld pool. In this regard the solution proposed by Nguyen et al. (1999) for the temperature field in general arc welding, subjected to a double ellipsoidal power

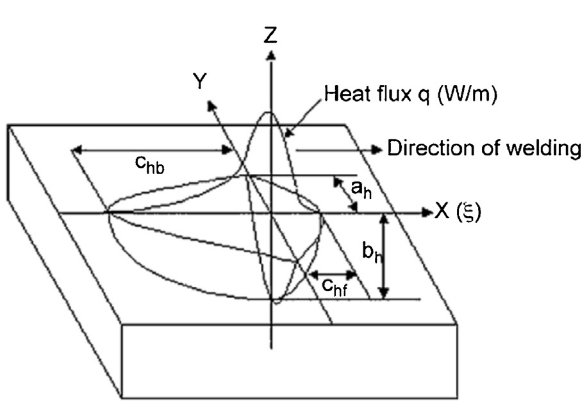

Fig. 1. Schematic diagram showing double ellipsoidal heat source.

density of moving heat source (Fig. 1), was found rather near to the experimental observations.

The solution proposed for the transient temperature area (T_d) at any point (x, y, z) of a semi-infinite thick plate from time, $t' = 0$ to $t' = t$, is stated as follows.

$$T_d = \frac{3\sqrt{3}.Q_{AW}}{2\rho.c.\pi\sqrt{\pi}} \int_0^t \left[\frac{dt'}{\sqrt{\left(12a(t-t')+a_h^2\right)}.\sqrt{\left(12a(t-t')+b_h^2\right)}} . \left(\frac{A'}{\sqrt{\left(12a(t-t')+c_{hf}^2\right)}} + \frac{B'}{\sqrt{\left(12a(t-t')+c_{hb}^2\right)}} \right) \right] + T_0 \quad (1)$$

where,

η,**V** and **I** are arc efficiency, arc voltage and arc current. The **ρ**, **c** and **a** are mass density, specific heat and thermal diffusivity of the workpiece. The $\mathbf{a}_h$, $\mathbf{b}_h$, $\mathbf{c}_{hf}$ and $\mathbf{c}_{hb}$ are the ellipsoidal heat source parameters defined by a position having a minimum power density of 5% to that of the center of the surface of the ellipsoid. Q_{AW} is the arc heat conveyed to the weld pool and evaluated by the following equation.

$$Q_{AW} = \eta.V.I \text{ Joule} \quad (2)$$

$$A' = r_f.\exp\left(-\frac{3(x-v.t')^2}{12a(t-t')+c_{hf}^2} - \frac{3y^2}{12a(t-t')+a_h^2} - \frac{3z^2}{12a(t-t')+b_h^2}\right) \quad (3)$$

$$B' = r_b.\exp\left(-\frac{3(x-v.t')^2}{12a(t-t')+c_{hb}^2} - \frac{3y^2}{12a(t-t')+a_h^2} - \frac{3z^2}{12a(t-t')+b_h^2}\right) \quad (4)$$

where, r_f and r_b are the fraction coefficients in front and behind the heat source, evaluated as

$$r_f = 2.c_{hf}/(c_{hf} + c_{hb}) \quad (5)$$

$$r_b = 2.c_{hb}/(c_{hf} + c_{hb}) \quad (6)$$

The arc efficiency for the TIG arcing process is considered as 75% and the suitable values of the ellipsoidal axes parameters are selected by measurement of weld pool geometry. The c_{hf} (in front of the heat source) and c_{hb} (behind the heat source) are considered as $c_{hf} = a_h$ and $c_{hb} = 2\ c_{hf}$ described by Goyal et al. (2009).

3. Experimental methods

Studies were carried out on AISI 8620 low alloy steel. Chemical composition of the steel plate was analyzed by spark emission optical spectroscopy as given in Table 2. The steel plate was used as substrate with the dimensions of 150 × 65 × 18 mm.

Prior to application of TIGA process the substrate surface was grinded leaving surface roughness of about 0.8 μm followed by solvent (Acetone) cleaning to remove any oily product present on it. The surface modification of workpiece was executed by autogenous (without filler) Direct Current welding power source model ESAB Aristo 2000-LUD 450 UW. The controlled fusion of the substrate

Table 2
Chemical composition of the AISI 8620 steel plate.

Chemical composition (Wt.%)										
C	S	P	Mn	Si	Cr	Ni	Mo	Al	Cu	Fe
0.23	0.002	0.01	0.69	0.21	0.63	1.19	0.19	0.02	0.02	rest