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Effect of mechanical activation on jell boronizing treatment of the AISI 4140

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ABSTRACT

The article presents the effect of mechanical activation on the growth kinetics of boride layer of boronized AISI 4140 steel. The samples were boronized by ferroboron + (SiO_2–Na_2O) powders for 873–1173 K temperature and 2, 4, 6 and 8 h times, respectively. The morphology and types of borides formed on the surface of AISI 4140 steel substrate were analyzed. Layer growth kinetics were analyzed by measuring the extent of penetration of FeB and Fe_2B sublayers as function of treatment time and temperature in the range of 873–1173 K. High diffusivity was obtained by creating a large number of defects through mechanical activation in the form of nanometer sized crystalline particles through the repeated fracturing and cold-welding of the powder particles, and a depth of 100 μm was found in the specimen borided by the 2 h MA powders, for 4 h and 1073 K, where 2000–2350 HV were measured. Consequently, the application conditions of boronizing were improved by usage of mechanical activation. The preferred Fe_2B boride without FeB could be formed in the boride layer under 973 K boronizing temperature by mechanically activated by ferroboron + sodium silicate powder mixture due to the decrease of the activation energy.

1. Introduction

Boronizing process is practised to increase the surface hardness and wear resistance of metals through diffusion of boron atoms into the metal substrate to form boride layer. It can be applied to a wide range of materials including ferrous materials, nonferrous materials and some super alloys [1,2]. Boronizing techniques could be roughly classified into three types: named as gaseous, liquid and solid methods. Three types of boronizing methods take gaseous, liquid and solid boron compounds as boron-yielding substances, respectively [3,4]. These three boronizing methods have certain disadvantages [5]: for gaseous boronizing, traditional gaseous boronizing agents are very sensitive to even the slightest traces of moisture, very poisonous, more costly and subject to explosion; for solid boronizing, the distribution of boron is not uniform and the sample needs to be frequently cleaned, and relatively high processing temperature and long process duration for getting an effective boride layer thickness is needed [6]; for liquid boronizing, a firmly adhering salt layer forms on the work pieces and this can be quite costly to remove after boronizing has been completed. In general, the thickness of boronized layer increases with the increase of boronizing temperature and time, but varies for different materials under the same boronizing conditions. Of the four methods, pack-boronizing is the most widely used in the industries due to its simplicity and cost-effectiveness [7,8]. For elimination of the disadvantage of solid boronizing mechanical activation can be applied to decrease the activation energy during boronizing. The other problems related with present boronizing techniques are the embrittlement of boride layer. In order to reduce or remove the embrittlement, several kinds of post boronizing treatment methods have been investigated: (1) laser treatment: post boronizing laser surface treatment can reduce the embrittlement of the boride layer [9,10]. The coarse, columnar structure with axial texture of boride layer could change into fine grain structure, which renders decrease of embrittlement of boride layer; (2) vacuum thermal diffusion: high-temperature vacuum diffusion could make FeB phase with high hardness and high embrittlement transformer into Fe_2B with relative low hardness and low embrittlement; and (3) quenching: quenching treatment can increase the hardness of iron and steel substrate, which would results in reduce of hardness gradient between boride layer and substrate, and so decrease embrittlement and increase the adhesion of boride layer to the substrate. The diffusion mechanism of boron atoms into ferrous alloys forms FeB and Fe2B intermetallic, nonoxide, ceramic borides [11]. Depending on the process temperature, the chemical composition of substrate materials, boron potential of medium and boronizing time, single Fe_2B or a double intermetallic phase (FeB, Fe_2B) is obtained by diffusing boron atoms into the surface of metallic materials. The particle size of the powders used in boronizing was a significant processing parameter and in some studies the particle size of powder decreased with the increased boride layer thickness [2]. Using mechanical activation (MA) technique, non-equilibrium phases can be produced.

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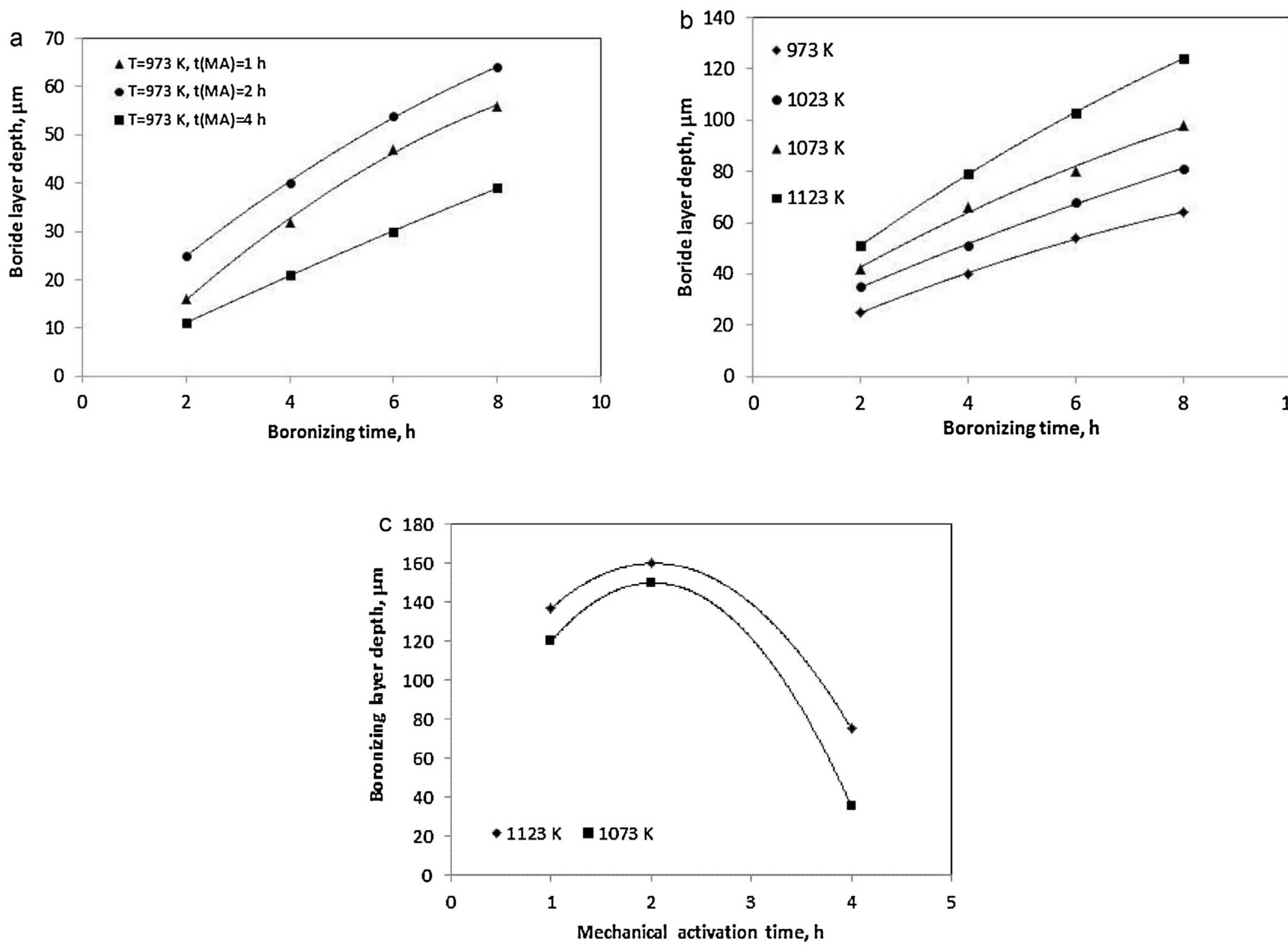

Fig. 1. The thickness of the boride layer for 2, 4, 6, 8 h at (a) 973 K under the 1, 2 and 4 h mechanical activation conditions, (b) 973, 1023, 1073 K and 1123 K for 2 h mechanical activation, and (c) effect of boronizing temperature on the boronizing layer depth.

The diffusion rates are influenced by the initial contact area and diffusion of the reactant species through the product phases [12]. For most solid-state processes, the initial contact area is fixed and diffusion rate is limited. Therefore, solid-state diffusions are essentially temperature dependent. This is not the case for MA induced reactions, since the diffusion can actually increase with increase in MA duration and with a change of phases [13]. With repeated fracturing and rewelding of the powder particles, the reaction area is increased, silting in an increase in chemical reactivity during MA. MA minimizes the effect of product barriers on the diffusion kinetics and increases the solid state diffusion at low temperature.In this study, the boron diffusion on boride layer is evaluated taking into account the effect of mechanical activation on growth kinetics of the boride layer during the boronizing process on AISI 4140 steel. The growth kinetics of the layer is analyzed by measuring the thickness of the layer as a function of the treatment time within the temperature range 873–1173 K. The main goal by mechanical activation was to reduce the embrittlement and improve the properties of boride samples. The jell boronizing with mechanical activated ferroboron–sodium silicate mixture has solved the embrittlement problems by making possible the diffusion of boron under 1073 K and 4 h boronizing conditions. The Fe_2B/FeB phase ratio was increased by using the mechanical activated boronizing powders, and the boronizing time was decreased as lower than 4 h and the temperature was decreased less than 1073 K.

2. Experimental

AISI 4140 steel, contained 0.40% C, 0.80% Mn, 0.25% Si, 1.00% Cr, 0.20% Mo, max. 0.04% S and max. 0.035% P, was chosen to be boronized by using jell boronizing technique. The surface of AISI 4140 steel samples was cleaned and polished before boronizing. The AISI 4140 steels were placed into a cylindrical stainless steel heat-treatment box filled by mechanically activated jell boron-yielding agents. The box was then placed in a pot furnace and heated to 873–1273 K for 2, 4, 6 and 8 h. At the end of the treatments, the box was removed from the furnace and allowed to cool. The boronized AISI 4140 steels were then removed from the box, cleaned and polished.

The boronizing of AISI 4140 steel was performed with mechanical activation of boron-yielding agents of at dose of 98 wt.%FeB + 2 wt.% (SiO_2–Na_2O). The ferroboron analysis was min. 18% B, max. 0.5 Al, max. 2.5 Si, max. 0.5 C and max 0.01 S. Before milling the ferroboron with sodium silicate, it was crushed, grinded and sized to a mean size of 150 μm, and after milling the size of the powders changed at the range of 60–150 nm. The mechanical activation was performed by spex type milling machine having 1200 rev/min, and 1/10 steel ball ratio (∅ = 6 mm). The microstructure of samples was analyzed by using XRD and SEM. The distribution profile of boron was analyzed using a GDOES (LECO GDS 850A). The micro-hardness was carried out by using a Vicker's hardness tester.