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Pack boronizing of AISI H11 tool steel: Role of surface mechanical attrition treatment

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ABSTRACT

The role of surface mechanical attrition treatment (SMAT) on pack boronizing of AISI H11 type tool steel is addressed. SMAT induced plastic deformation, enabled nanocrystallization at the surface, reduced the grain size and increased the volume fraction of non-equilibrium gain boundaries, increased the accumulation of defects and dislocations at the grain boundaries and within the grains. These features helped to promote the diffusion of boron during boronizing and increased the case depth and hardness of the borided layer. Duplex treatment on SMATed H11 steel samples helps to achieve a higher case depth when compared to the single stage treatment. The findings of the study suggest that SMAT can be used as a pretreatment for boronizing of H11 tool steel.

1. Introduction

The surface properties of materials such as wear resistance, friction, corrosion resistance and oxidation resistance play a key role in determining the service life of many engineering components, which lead to the development of numerous surface modification methods. Boronizing is a thermo-chemical surface treatment process that involves diffusion of boron atoms into the surface of metal/alloy to produce a layer of borides of the corresponding metal/alloying elements [1,2]. The major advantages of surface treatment by boronizing are its ability to impart high hardness, excellent abrasion and wear resistance and, oxidation resistance compared with other similar treatments [3–9]. Tool steels, particularly the H type are commonly used in many industrial applications. Being an alloy steel, improving the surface reactivity and accelerating the diffusion of boron is a challenging task.

It is well known that in ultra-fine grained (UFG) and nanocrystalline materials, the presence of a large number of grain boundaries and triple junctions could act as fast atomic diffusion channels [10,11]. In the past decade, diffusion behaviour in UFG or nanostructured materials produced by severe plastic deformation (SPD) has become an attractive topic, since SPD is a promising route for producing bulk nanostructured materials with enhanced properties [12,13]. Surface mechanical attrition treatment (SMAT) is a surface severe plastic deformation method that enables nanocrystallization at the surface of various metallic materials [14–21]. SMAT enhanced the kinetics of diffusion of nitrogen, aluminium, chromium and zinc during nitriding, aluminizing, chromizing and diffusion zinc coatings, respectively [22–26]. These processes, however, are relatively low temperature processes when compared to boronizing. Hence, materials subjected to SMAT could maintain their nanostructured surface layer. In addition, the increase in grain size during these processes is rather limited to cause any significant influence on the kinetics of diffusion of the corresponding elements. However, the temperature employed for boronizing of most of the ferrous alloys is of the order of 1173–1273 K for a few hours [3–9,27] and, hence it is very difficult to realize the benefits of surface nanostructuring at such conditions. This has also been addressed in our earlier paper on the effect of SMAT on boronizing

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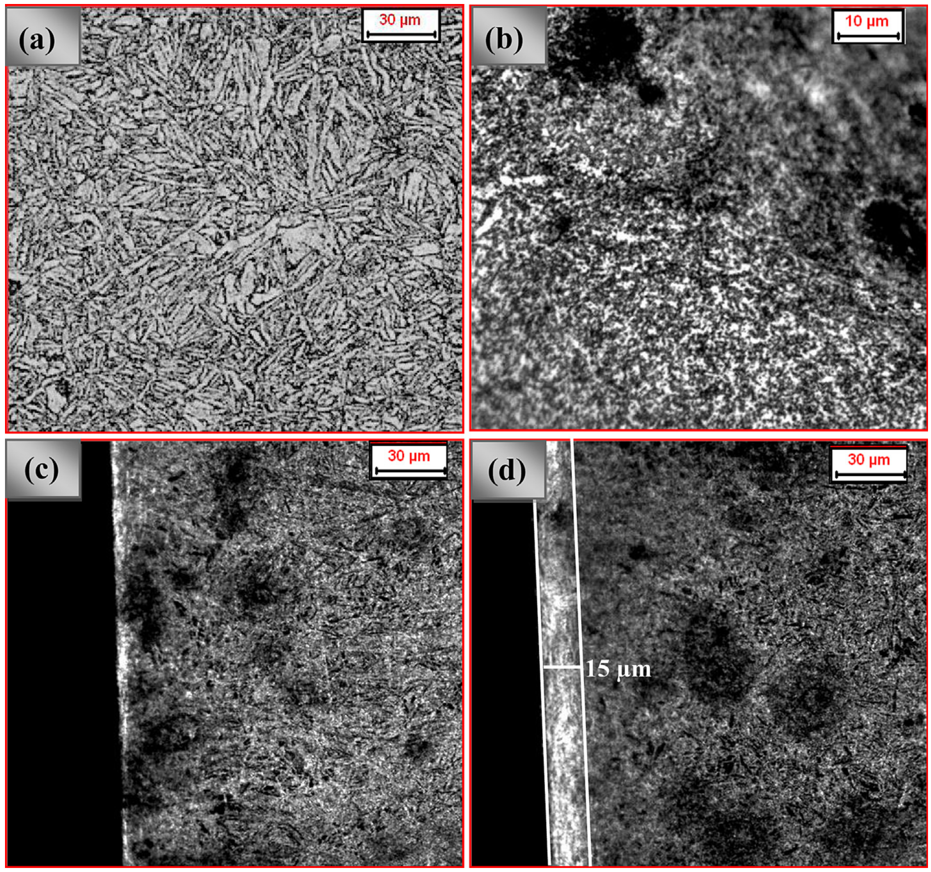

Fig. 1. Optical micrographs taken at the surface (a, b) and cross section (c, d) of AISI H11 tool steel: (a, c) untreated; and (b, d) after SMAT using 8 mm ∅ 316L SS balls for 3600 s (c, d – dark field images).

of EN8 steel [28]. Surface nanocrystallization by SMAT offers the benefit of formation of borided layers at relatively lower temperatures. Xu et al. [27] have shown that boronizing of SMATed H13 steel could be achieved at 973 K for 28,800 s. In our earlier study, we have shown that it is possible to get a reasonably thick boronized layer on SMATed EN8 steel at 923 K for 25,200 s [28]. However, such a long processing time is not practicable for many industrial components.

Boronizing of various types of tool steels such as H11 type [29], H13 type [27,30], D type [31–34], M type [35,36], W type [37,38] and hot work tool steel X38CrMoV5-1 [39] has been studied earlier. Studies on boronizing of H type hot work tool steels are rather limited. The effect of SMAT on boronizing of AISI H11 tool steel is not studied earlier. Since boronizing of alloy steels requires a higher temperature of the order of 1223 K, it would be interesting to know to what extent the surface nanocrystallization generated by SMAT will be useful in promoting the kinetics of diffusion of boron. In addition, it is worthwhile to verify the effectiveness of a duplex treatment similar to the one employed in our earlier study [28]. The present paper aims to address the above issues.

2. Experimental details

AISI H11 steel square blocks (70 mm × 70 mm and 8 mm thick), having a chemical composition (in wt. %) C: 0.40; Si: 0.84; Mn: 0.34; P: 0.012; S: 0.016; Cr: 4.80; Mo: 1.19; Ni: 0.26; Cu: 0.07; Ti: 0.005; V: 0.34; Fe: balance; were used as substrate materials. These samples were procured in heat-treated (at 1020 °C for 2 h followed by quenching in air) condition. Generally, hot work tool steel that contains about 0.4% C and 5% Cr is likely to form carbides of $M_{23}C_6$ and/or M_7C_3-type (ferrite and spheroidized carbides). In addition, it is alloyed with small amounts of vanadium and molybdenum. Hence, to avoid the precipitation of secondary carbides at the grain boundaries, heat treatment of tool steels is performed at ~1020 °C to achieve proper functionality of the tools. The H11 steel samples were degreased using acetone and subjected to SMAT using 8 mm Ø 316L stainless steel (SS) balls for 3600 s. All experiments were performed at a fixed frequency of 50 Hz and under vacuum. The

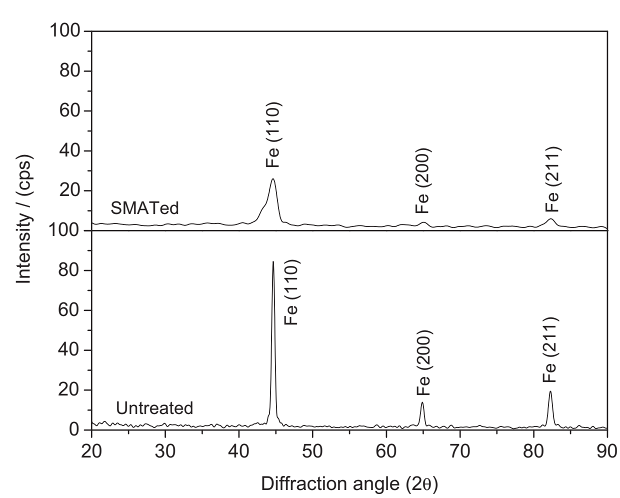

Fig. 2. XRD patterns of untreated AISI H11 tool steel and those subjected to SMAT using 8 mm Ø 316L SS balls for 3600 s.