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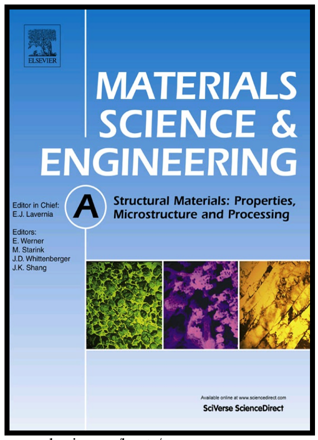

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Effect of welding thermal cycle on microstructural evolution of Al–Zn–Mg–Cu alloy

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ABSTRACT

Al–Zn–Mg–Cu alloys are used extensively in high-speed train applications; however, the occurrence of softening in the heat-affected zone after welding limits their development. In this work, the effect of the welding thermal cycle on the softening and aging behaviors of a 7xxx aluminum alloy was investigated by examining the state of the strengthening precipitates. The microstructure and solvus temperature range of the precipitates of 7N01P-T4 were characterized using TEM and DSC analysis, respectively. It was found that the softening behavior of the aluminum alloys was closely related to the volume fraction and size of the hardening precipitates, which were greatly affected by the peak temperature of the welding thermal cycle. In addition, η′ and η precipitates were observed to be primarily responsible for the increase in the mechanical and electrical properties during the room-temperature natural aging. A phenomenological connection was thus uncovered between the characteristic parameters of the thermal cycle and the precipitation behavior, providing insight for the design of the welding process for 7N01 alloys.

Keywords: Al–Zn–Mg–Cu alloy, thermal cycle, softening behavior, TEM, precipitation

1. Introduction

With the trend of the development of light-weight structures, high-strength aluminum alloys have been used extensively. Alloy 7N01, a heat-treatable Al–Mg–Zn alloy, was developed for train body applications in the high-speed train industry [1]. In these applications, the alloys must be joined using a welding process; therefore, the effect of welding on the material properties is an important consideration. Unfortunately, softening generally occurs in the heat-affected zone (HAZ) of heat-treatment-strengthened Al alloys during the welding process. In addition, the location of the softened zone is typically a potential fatigue failure location during in-service processes, which seriously affects the safety of the structure, reported by Grong [2]. Therefore, in the present research, the coupling of dissolution and precipitation in the HAZ and the peak temperature in the thermal cycle was investigated, as it is important for clarifying the softening problem in the 7N01 welding process.

Unlike heat treatment, a welding thermal cycle is a rapid heating and cooling process. The dissolution and precipitation of strengthening phases in the HAZ occur during the welding cycle and subsequent natural aging. Bjørneklett et al. [3] used process modeling techniques to develop a model that provides a sound basis for predicting the HAZ strength loss during welding of Al–Zn–Mg alloys as well as the resulting recovery of strength after prolonged natural aging. Because the HAZ of the weld was too narrow to prepare test specimens, Sato et al. [4] performed thermal simulation to evaluate specimens with a wide uniform temperature zone, and subsequent transmission electron microscopy (TEM) observation revealed that the precipitate distribution corresponded to the hardness profile in the HAZ of Al alloys. Hansen et al. [5] evaluated the effect of time–temperature ranges of the precipitate transformations of 7000 series alloys during the aging process. In addition, the dependence on the quenching temperature was analyzed using differential scanning calorimetry (DSC) and TEM. The mechanical properties of precipitation-strengthened Al alloys were observed to be closely related to the volume fraction and size of the hardening precipitates. Zhang et al. [6] monitored the evolution of the