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Finite Element Simulation and Experimental Verification of HAZ Softening during Welding of Aluminum alloy 7075

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ABSTRACT: The one-of-a-kind properties of series 7xxx aluminum alloys such as high strength, relatively low density, good formability, and good resistance to stress corrosion cracking have made this class of materials a good choice for aerospace, automobile, and marine industries. Watertight, low weight, and fast procedure are the reasons why welding is used in many industries. The heat that welding produces causes many problems like softening in the heat-affected zone. In this research with the use of a 3-D finite element model, the heat transfer of the Al-7075-T6 is investigated and verified by comparing them with the experimental model, and the reduction of hardness in the heat-affected zone of the aluminum was predicted with good precision. In the next step, the softening of HAZ due to welding was measured with microhardness. With the use of the FEM model kinetic of over-aging was measured. The results show hardness of the alloy has two sources i.e., age-hardening and work-hardening. It seems welding eliminates the effects of age-hardening but has no effect on the hardness that comes from work hardening. Also, the decrease in the hardness of the solution-annealed area can be recovered through proper heat treatment. However, it is unrecoverable in the over-aged area.

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1- Introduction

High strength, low density, good ductility, and resistance to stress corrosion cracking (SCC) have made 7000 series aluminum alloys to be considered in shipbuilding industries [1]. Aluminum alloys are aged to precipitate after dissolution heat treatment and rapid cooling. As a result of aging, microscopic particles begin to form that act as barriers in grains and grain boundaries [2]. Fu et al. [3] used three aging methods to investigate the effect of aging heat treatment on restoring the lost hardness of T6-7005 alloy; as a result, they realized that artificial aging is better than the other two modes to restore the lost hardness during welding. One of the common problems in the welding of work-hardened, heat-treatable aluminum alloys such as the 7xxx, is strength loss in the heat-affected zone (HAZ). [4]. Richardson et al. [5] plotted the hardness profile for the welded 7075 alloy in one-day and 30-day periods after welding. During welding, the hardness dropped to about 80, but the 30-day aging (natural aging) had it recovered, and the hardness increased to about 100. Finite element simulation has been employed for the examination and analysis of various aspects of welding [6,7].

So far, only a few studies have been conducted to predict the softening behavior of 7xxx aluminum alloys, which include the exceptionally strong 7075 aluminum alloy. This paper aims to examine the impact of welding heat input on the hardness loss in this alloy and propose predictive relationships for estimating its hardness.

2- Materials and Methods

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This article utilizes a 5mm thick Al-7075-T6 alloy.

the original samples were welded using the variables specified in Table 1.

Cross-sections were prepared for metallography. The first set of sections underwent metallographic analysis and hardness measurements after 7 months. For the aging process, natural conditions were employed, maintaining room temperature and an air atmosphere. As for the second set of sections, they were prepared for

To predict the decrease in hardness for non-isothermal conditions, Papazian [8] used Avrami's relationship as equation (1):

$$\begin{cases} y = 1 - \exp(-k^{n}.t^{n}) \\ k = k_0.\exp(\dfrac{-Q}{RT}) \end{cases} \quad (1)$$

4- Results and Discussion

The simulated models were evaluated against real models to validate their accuracy (Figure 2).

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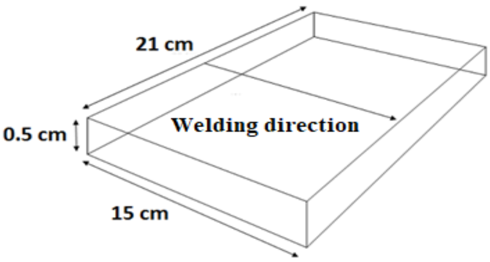

Fig. 1. Schematic of the aluminum sheet

Table 1. Welding variables of the samples

Sample no.	current (A)	Voltage (V)
1	160	15
2	170	15
3	190	15

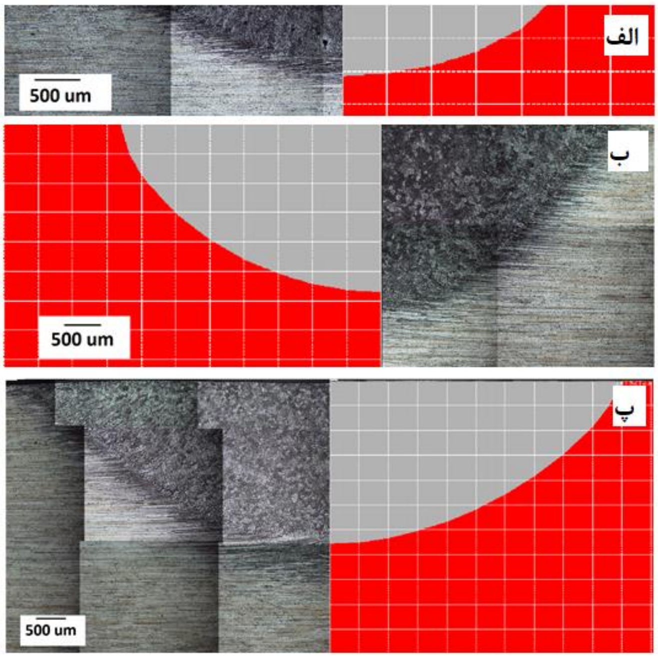

Fig. 2. Validating the finite element models using the dimensions of the weld pool

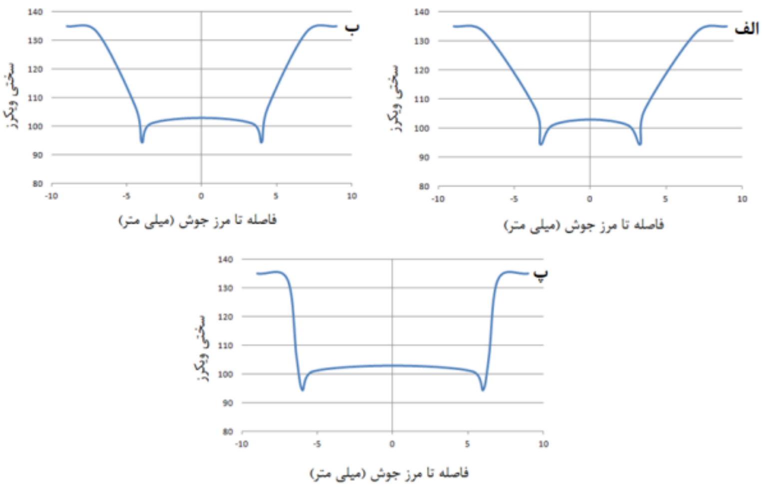

Fig. 3. Hardness according to the distance from the weld line

At a certain distance from the welding line of all samples, the hardness drop is more severe, which is caused by solution annealing. As shown in Figure 3, the hardness decreases as it approaches the weld line, which indicates the softening behavior of the heat-affected zone.

The hardness of the samples after 7 months indicates that the softening near the weld line has been partially compensated. However, there is still a slight difference in the hardness of the base metal (133 Vickers).

The aging percentage at each temperature is determined by equation (2):

$$y = y_1 + y_2 \times (1 - y_1) \quad (2)$$

Where y_1 represents the initial aging and y corresponds to the total percentage of aging at each temperature. It should be noted that the percentage of aging in the second stage ($y2$) should be obtained from the percentage of aging in the first stage. The hardness of the alloy can be influenced by both aging and cold work. However, during welding, when exposed to the heat from the heat source, the hardness tends to decrease. This effect primarily impacts the aging process, resulting in changes, while the hardness caused by cold work can manifest as recrystallization. Figure 4 illustrates the heat-affected area of all the samples. As observed, no recrystallization occurred after welding, indicating that the impact of cold work has not diminished.

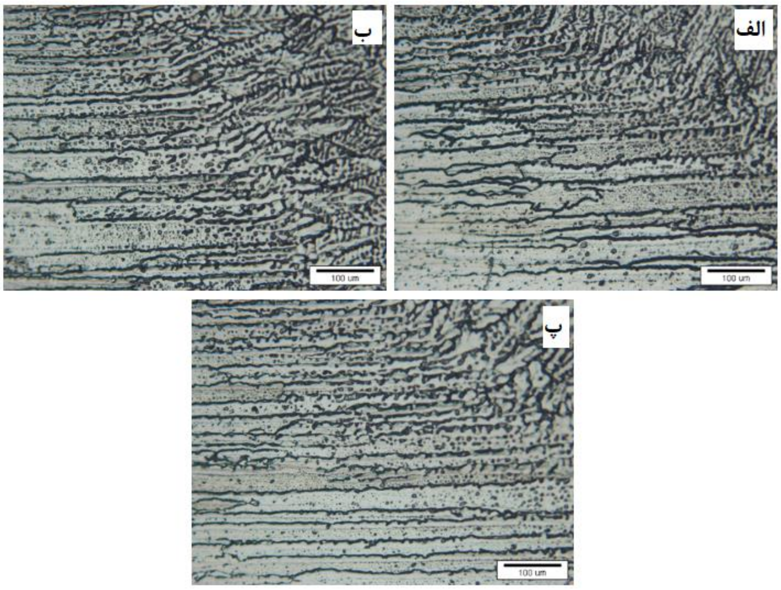

Fig. 4. Heat-affected zone in samples

5- Conclusions

- During welding, the hardness in the heat-affected area decreases, especially at higher input temperatures, leading to complete loss of hardness due to aging in all samples.
- While appropriate heat treatment can compensate for hardness drop in the solution-annealed area, restoration is not possible in the super-aged area. Artificial aging is the preferred method, but this study utilized natural aging, resulting in approximately 97% restoration of the alloy's initial hardness.
- Moving towards the weld line from the heat-affected zone boundary, the temperature range where hardness drops to the annealing condition expands.

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