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Review

Research progress of residual stress determination in magnesium alloys

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Abstract

With the research development of the magnesium alloys, the deformation or stress corrosion induced by residual stress (RS) attracted extensive interests in industry and research efforts extensive. However, there are relatively few studies on the RS of magnesium alloys in the world. The generation cause of RS in magnesium alloys was analyzed at first. Several methods of determinate the RS, including destructive methods (drilling hole, crack compliance, layer exfoliation etc.) and non-destructive methods (X-ray Diffraction, Neutron Diffraction, Short Wavelength X-ray Diffraction) were summarized. The factors that influence the measuring accuracy of XRD method were emphasized. The research trends of RS in magnesium alloys were put forward.

Keywords: Residual stress; Magnesium alloys; Stress generation; Stress measurement.

Contents

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1. Introduction

As lightweight structural materials, magnesium alloys have been widely used in aviation, automobile and electronics industry [1]. The plastic processing methods of magnesium alloys are commonly used in extrusion, rolling and forging. Residual stress (RS) in the magnesium alloys would lead to distortional failure, deformation, stress-corrosion cracking, or fatigue of the workpiece which declines the production and increases costs [2,3]. So that it is important to determinate RS in magnesium alloys. However, research on the RS mainly concentrated in the steel, aluminum alloys and other traditional metal materials. Due to magnesium alloys' crystal structure(HCP) and properties, it is difficult to determinate the RS accurately. In this review, the researches on RS in magnesium alloys were analyzed, and the development tendency of research about the RS in magnesium alloy was forecasted.

2. Residual stresses generation in magnesium alloys

RS are stresses that remain in a solid material after the original cause of the stresses has been removed. It can occur through a variety of mechanisms including inelastic (plastic) deformations, temperature gradients (during thermal cycle) or structural changes (phase transformation).

(1) Plastic deformation: During the process of plastic deformation, the material often has asymmetric shape, force states and inhomogeneous properties. Therefore, when processing is finished, materials would rebound unevenly and generate RS [7].
(2) Temperature variation: The difference of temperature distribution in the process of heat treatment will make the volume of each part of the material change unevenly [8,9]. Quenching would induce tensile RS in the central area, compressive stresses at the surface [10–12]. As a lightweight structural material, magnesium alloy has some advantages in friction stir welding. However, due to the large temperature variation gradient between the base metal and welding area, the RS will be generated [13,14].
(3) Structure transformation: The Austenite and Martensite transformation in the steel would lead to the volume change. According the Mg-Al phase diagram [6], aluminum element content in α-phase is relatively low, it is not easy to crystallize plenty of dispersed β-phase($Mg_{17}Al_{12}$) so that the phase transformation only could generate fewer RS.

The distribution of RS in the welded joints is extremely uneven, such as the friction stir welding workpiece between the same kind of magnesium alloy [4], and hybrid laser-TIG welding workpiece between the magnesium alloy and steel [5], which would cause cracking and decrease the workpiece's service life. Meanwhile, during the plastic deformation process, temperature variation and microstructure transformation could not be completely uniform, which would lead to the nonuniform distribution of RS.

It is very important to grasp the distribution of RS in the actual production process before eliminating or reducing stress which will lead to workpiece deformation or crack. However, with close-packed hexagonal structure, magnesium alloys are more likely to be anisotropic than the steel [15,16]. Both the texture and large size of grain would make the residual stress determination more difficulty. Thus, the methods to determine RS are necessary to be known.

3. The methods of determination residual stresses in magnesium alloys

There are several methods to determine the surface RS, such as X-ray diffraction (XRD) [17–19], drilling hole using strain gauge measuring [20–23], ultrasonic wave [24,25], hardness indentation [26–28] etc. As to the internal RS measuring, it is much more complicated and expensive. The destructive method of layer exfoliation and compensation is used traditionally. The non-destructive methods appeared in recent years using neutron diffraction, synchrotron radiation, short wave X-ray diffraction.

The several used methods in practice were introduced.

3.1. XRD method

The principle of X ray diffraction is based on the Bragg's law formula and the elastic mechanics. It is considered that the lattice strain induced by RS can reflect macroscopic strain. RS is calculated by measuring the interplanar spacing which has the high accuracy. In recent years, Recently, a two-dimensional (2D)X-ray detector has been readily available to allow the collection of the Debye–Scherrer ring (DSR) for the stress calculation .Compared to the traditional method called $\sin^2\psi$, this method could gain more information, and be more convenient [29–31].

The result of XRD method is the average value of many grains, thus it would be affected by material surface quality and diffraction planes [32]. The common X-ray RS measurement was widely used. Because of the limited penetration ability of ordinary X ray, the condition of σ_{zz} is usually satisfied. Meanwhile, the ψ angle is defined as the angle between the diffraction crystallographic planes' normal line and material surface normal line. If RS existed in the workpiece, the interplane spacing in the workpiece material will be changed. for the polycrystalline material, the change of the interplane spacing under different angles is different. Under the condition of continuous and isotropic material, it is necessary to test the linear relationship between $\varepsilon_{\varphi\psi}$ and σ_{φ}-$\sin^2\psi$ under different ψ angle, so as to realize the measurement of RS. For example, Kouadri and Barrallier [33] had done research on RS in laser welding of AZ91 magnesium alloy sheet measured by $\sin^2\psi$ method, and obtained the distribution of RS in the welding zone and the base metal. Outeiro et al. [34] acquired the distribution of RS in AZ31B magnesium alloy processed by cryogenic cooling, and the results showed that the

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