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Constrained groove pressing for sheet metal processing

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ABSTRACT

Constrained groove pressing (CGP) is a modern technique for developing ultrafine grain structures in sheet metals for inducing superior material properties. In CGP, the sheet metal specimens are subjected to repetitive corrugating and straightening under the plane strain deformation condition by utilizing alternate pressing with the asymmetrically grooved dies and flat dies. This induces a great amount of plastic strain in the sheet metal specimen without changing its initial dimensions. Over the last few years, CGP has gained significant importance for it being one of the most suitable techniques to fabricate sheet metals with superior and attractive properties. CGP can effectively refine the grain structure to a sub-micrometre level and at times, even to a nanometer level. Materials processed by CGP exhibit very high strength, high hardness and many other desirable properties. Numerous investigations were made on different materials like aluminium, copper, low carbon steel and nickel, and their properties were well documented in the scientific literature. This review summarizes most of the scientific results that were obtained by applying CGP to various materials and gives an outline of the applications of CGP in various industries. This review also discusses about the future scope of research on CGP and its benefits.

Contents

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1. Introduction

Materials with superior mechanical properties are desirable because they have a wide range of applications in various industries like aerospace industry and automobile industry [1]. One of the ways to improve the mechanical properties of metals and alloys is to reduce their average grain size to ultra-fine grain (UFG) range [2,3]. Grain refinement increases the strength of the material and strength-to-weight ratio which are desirable properties. UFG materials have relatively higher strength at room temperature and can be used in super forming operations at elevated temperatures [4–6]. Therefore, fabrication of UFG materials is of great importance. There are two ways to synthesize UFG materials, viz., bottom-up approach and top-down approach. In the bottom-up approach, the nanostructure is produced through atom by atom and layer by layer arrangement. But, this approach has a disadvantage. It leads to formation of porous structure which makes it unsuitable for industrial manufacturing. The other approach, the top-down approach, is free from this disadvantage. Severe Plastic Deformation (SPD) is one of the most efficient ways to produce UFG materials through a top-down approach [7–9].

SPD involves the increase of dislocation density by heavy uniform deformation of materials, formation of dense dislocation walls and transformation of dislocation walls into high-angle grain boundaries. Materials produced by SPD have non-porous structure, have superior properties and also have proper dimensions for mechanical and physical testing. SPD increases the tensile strength and also improves other mechanical properties like superplasticity, fatigue properties and fracture behaviour [10–12]. The drawback of UFG materials is their limited ductility [13,14]. One of the ways to enhance ductility in UFG materials is to explain the change in the deformation mechanism in an ultrafine-grained microstructure which is mainly characterized by high-angle boundaries and a large volume fraction of non-equilibrium grain boundaries [15].

Over the past decades, many SPD techniques have been proposed to produce UFG materials. Some of these methods are equal channel angular pressing (ECAP) [16–23], accumulative roll bonding (ARB) [24–29], high pressure torsion (HPT) [30–37], repetitive corrugation and straightening (RCS) [38–41], constrained groove pressing (CGP) [42–44], constrained groove rolling (CGR) [44], severe torsional straining (STS) [45–49], cyclic extrusion compression (CEC) [50], twist extrusion (TE) [51] and friction stir processing (FSP) [52]. Of these, ARB, CGP, RCS and CGR are used to fabricate plate shaped materials or sheet metals. Among them, CGP is one of the most suitable techniques for fabricating sheet materials with superior and attractive properties.

2. Principles of constrained groove pressing

2.1. Process of CGP

The technique of CGP was developed by Shin et al. [42]. In the CGP process, a sheet specimen is subjected to orthogonal shear deformation by repetitive pressing under grooved dies and flat dies alternatively [42]. Schematic diagram of CGP technique is shown in Fig. 1. Firstly, a pair of asymmetrically grooved dies which are tightly constrained by cylinder wall is prepared. The sample is placed in between the dies and the pressing is performed such that the gap between the upper die and the lower die is same as that of the sample thickness. This results in pure shear deformation under plane strain condition in the inclined region of the sample (single hatched area in Fig. 1(b)). However, the flat region remains undeformed (unhatched