

7th HPC 2016 – CIRP Conference on High Performance Cutting

Cutting forces and mechanical resistance of pure titanium processed by equal channel angular pressing

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Abstract

Implants are usually manufactured in titanium alloys due to their biocompatibility and high corrosion resistance. The additional elements present in titanium alloys increase the mechanical properties but also increase the possibility of infectious-inflammatory processes in the implanted region. Commercially pure titanium (CP Ti) has lower mechanical properties, but it can be processed by severe plastic deformation for grain refining and enhancement of mechanical behavior. This paper compares the machinability of different workpieces, manufactured in CP-Ti and CP-Ti powder processed by Equal Channel Angular Pressing (ECAP), using cutting forces as the reference parameter. Although mechanical properties are improved, cutting force experiments show that extruded specimens presented same level of machinability of CP-Ti bar.

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Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair Prof. Matthias Putz

Keywords: Metal Forming, Titanium, End Milling, Force

1. Introduction

Recently, the use of titanium and its alloys on biomedical application has grown, especially in implants, pins and prosthesis. The additional elements make the mechanical properties similar to the bone qualities, enhance the ultimate tension and reduce the Young module, but, on the other hand, the biocompatibility can be compromised. Elements like vanadium present in the Ti-6Al-4V alloy, widely used in implants, can eventually affect biocompatibility [1].

The enhancement of mechanical properties of commercially pure titanium (CP Ti) is needed for biomedical applications, specially orthodontic ones where higher strength is required. The quest for increased mechanical strength for CP Ti focuses on the impact of the average grain size on the mechanical properties of metallic materials. The Hall-Petch relation shows the improvement of the mechanical properties produced by grain refining [2].

Obtaining ultrafine granular structures with severe plastic deformation (SPD) processes has attracted great interest in recent decades. These processes involve high strain values and, consequently, the extreme reduction of the grain size. Among the SPD processes, Valiev et al. [3] claimed that equal channel angular pressing (ECAP) is the most attractive because of its efficient mechanism for reducing grain size, obtaining metallic nanostructured materials. Zhao et al. [4] confirmed that there is excellent strengthening after several ECAP passes with the yield strength increasing from 275 to 710MPa.

The raw material used in angular extrusion may be either solid metal or titanium metal powder. When ECAP is done using metal powder, it has a double objective: to consolidate the particles of powder and to refine the grain. Furthermore, the material presents macro and micro porosities that allow the absorption of bone tissue into the pores, enhancing osteointegration, stability and lifetime of the material, important properties for biomedical implants [5].

Medvedev et al. [6] showed that fatigue performance of ECAP-processed CP Ti was superior to that of conventional Ti-6Al-4V suggesting that ECAP combined with thermo-mechanical processing provides a useful method to create CP Ti semi-products that are promising substitutes for Ti alloys in medical implants. For example, the spring-loaded ECAP process, proposed by Jin et al. [7], is a sequential process of multi-stage forming to produce a pin-shaped part or shafts with high strength. The ultimate tensile strength of the microstructure-refined bolts formed by the ECAP process was approximately 6.2% higher than of the one manufactured by conventional bolt forming process.

Although threaded implants can be manufactured by plastic deformation, the thread geometry can be produced by machining processes, without affecting the achieved mechanical bulk properties of the workpiece. Also, machining guarantee higher accuracy or precision as in tapping and thread milling [8]. Thread milling allows cutting velocities that are not connected directly to feed velocity, essential when a brittle (and nanostructured) material needs to be machined because it could not support high feed velocities as the thread pitch per revolution. In order to machine threaded implants after ECAP, milling studies need to be done to analyze its machinability in this process.

Titanium alloys are regarded as hard-to-machine materials [9, 10] and although you can find several literature references on the effect of grain refinement in the mechanical behavior of materials, articles regarding the effect on their machinability is almost nonexistent. Arrazola et al. [11] studied the machinability results carried out for Ti555.3, applied to aeronautic industry, compared with the Ti-6Al-4V. They analyzed variables such as cutting forces, chip geometry and tool wear and it is presented the occurrence of the diffusion process leading to the formation of a layer of adhered material composed of Ti and TiC on the rake face for both Ti alloys. Thus, it becomes important to evaluate the machinability of nanostructured titanium comparing the cutting forces during the machining process and verifying if there is remaining Ti adhesion on the tool.

This article is part of a research that aims at the development of nanostructured pure titanium for use in surgical implants. In this work, pure titanium synthesized by powder metallurgy is processed by ECAP in order to consolidate the particulate material and reduce the size of the grains to increase the mechanical properties. A comparison of the machinability, based on the cutting force, of different workpieces produced by ECAP, with different number of passes, using CP-Ti and Ti powder is presented.

2. Equal channel angular pressing technique

Equal channel angular pressing is now the most popular and developed SPD technique and according to Valiev and Langdon [12], it is an especially attractive processing technique for several reasons:

- It can be applied to large billets, therefore having the potential for producing materials which can be used in a wide range of structural applications;

- It is a relatively simple procedure that is easily performed on a wide range of alloys and uses equipment that is available in most laboratories;
- Reasonable homogeneity is attained through most of the as-pressed billet;
- The process may be scaled-up for pressing relatively large samples.

Conventional ECAP process is shown schematically in Fig. 1a. The metal sample is pressed by a plunger into the die through a channel that is bent by an abrupt angle and has the same cross sectional area through the whole extension. The material is plastically deformed by simple shear as it passes on the intersection of the channels and the more abrupt is the angle, the greater the strain imposed to the metal billet. Sample can be fabricated in the form of a rod or a bar and it is machined to fit within the channel. Despite the introduction of a very large strain when the sample passes through the shear plane, it emerges from the die without experiencing any change in the cross-sectional dimensions, as illustrated by the figure. This figure also defines three separate orthogonal planes: X is the transverse plane, perpendicular to the flow direction; Y is the flow plane which is parallel to the side face of the billet; and Z is the longitudinal plane parallel to the top surface of the billet.

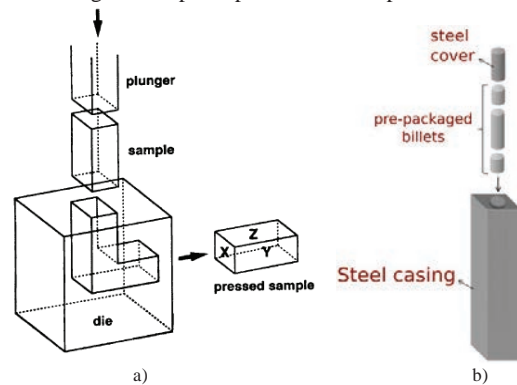


Figure 1. a) Schematic illustration of a typical ECAP facility: the X, Y and Z planes denote the transverse, the flow and the longitudinal plane, respectively [12]; b) Cartridge assembly for processing the compressed powder in the titanium ECAP matrix.

3. Experimental set-up and test procedure

3.1. Workpiece description

Two workpiece materials are used for comparison: commercial pure Ti taken from a slab rolled and annealed is used as reference, (sample CP Ti); and Ti powder pressed and deformed in two ECAP passes, (sample Ti 2x). It was used commercially pure titanium grade 2 [13]. Sample CP Ti presents a granular non refined structure, as showed in Fig. 2a. It is a homogenous grain structured with polygonal crystals, typically equiaxial pure metal with approximately 30 μm grain size in average.

For the Ti 2x sample, a uniaxial pressing is done in room temperature using 730 MPa pressure on pure titanium grade 2 powder from Instituto Nacional de Tecnologia (INT) with granulometry smaller than 149 μm and chemical composition according to grade 2 [13].

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