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Procedia CIRP 8 (2013) 481 – 486

www.elsevier.com/locate/procedia

14th CIRP Conference on Modeling of Machining Operations (CIRP CMMO)

A DoE approach to hole quality evaluation in drilling of an electron beam melted titanium aluminide

Paolo Claudio Priarone [a,*], Suela Ruffa [a], Joel Sauza Bedolla [a], Luca Settineri [a]

[a] *Politecnico di Torino, Department of Management and Production Engineering, Corso Duca degli Abruzzi 24, 10129 Torino, Italy*

* Corresponding author. Tel.: +39-011-0907206; fax: +39-011-0907299. *E-mail address*: paoloclaudio.priarone@polito.it.

Abstract

Gamma titanium aluminides are heat-resistant intermetallic structural alloys with many attractive properties such as low weight, high stiffness, high refractoriness and high temperature strength. These alloys are excellent candidates to be used as alternative to Nickel-based superalloys for thermally and mechanically stressed components in aerospace and automotive engines. The material properties, however, lead to γ-TiAl difficult machinability, resulting in poor surface quality. In this paper, the geometrical accuracy of holes drilled on a Ti-48Al-2Cr-2Nb γ-TiAl component, produced via Electron Beam Melting (EBM), is analyzed. Particularly, the Design of Experiments (DoE) technique was selected because of its usefulness in determining simultaneously the individual and interactive effects of many variables, that could affect the output results. Experiments were conducted with uncoated carbide drills, varying the cutting parameters. Machined holes were measured by means of a coordinate measuring machine. Hole quality was assessed focusing on the dimensional and geometrical errors, in terms of both cylindricity and roundness, and taking into account the tool wear and the hole depth.

Selection and peer-review under responsibility of The International Scientific Committee of the "14th CIRP Conference on Modeling of Machining Operations" in the person of the Conference Chair Prof. Luca Settineri

Keywords: Gamma titanium aluminide; drilling; hole quality; DoE

1. Introduction

Titanium aluminides (TiAl) are intermetallic alloys, compounds mainly formed by two metals, Titanium and Aluminum, showing structures and properties completely different from their basic constituents. In this materials group, gamma titanium aluminides (γ-TiAl) have received an increasing industrial and academic attention in recent years. Showing an attractive combination of properties, they have been evaluated as key contenders for advanced structural applications in automotive and aerospace sectors. These alloys have significantly lower density in comparison to Nickel-based superalloys, together with high strength-to-weight ratio, high temperature strength, and good oxidation and fatigue resistance [1]. Commercial interest in TiAl is centered mainly in the aerospace and automotive sectors, and possible fields of application can be detected both in rotating and non-rotating parts for military and civil applications. Components that could be made out of this alloy are low pressure turbines blades, compressor vanes, swirl nozzles, automotive engine valves and turbochargers [2-5]. γ-TiAl alloys are regarded as difficult-to-cut materials, because of their high hardness and brittleness, low thermal conductivity, high chemical reactivity, and strong tendency to hardening [6]. Poor machinability and, furthermore, the high manufacturing costs, limit the widespread use of those materials in the market. Few researches have been addressed on drilling of gamma titanium aluminides [7-10], and these studies highlighted that drilling can be accomplished, but with poor productivity and workpiece integrity. In addition, the machinability results are strongly dependent on the specific alloys and on the production technology used.

In recent years, additive manufacturing has emerged as a promising fabrication technology for metal parts, able to produce complex shaped components using three

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doi:10.1016/j.procir.2013.06.137

dimensional computer aided design (CAD) data and starting from a precursor powder that is consolidated layer-by-layer by sintering or by melting, using either a laser or an electron beam as energy source. Fully dense γ-TiAl near-net-shape components were obtained via electron beam melting processes. EBM is appealing for several reasons: time-to-market reduction, high geometrical freedom, and the possibility to create complex parts with internal cavities and channels. The un-melted powder can be recycled without appreciable modification of its chemical composition and physical properties, reducing the overall waste material. In addition, the process is carried out in vacuum, which makes it suitable for materials with a high affinity to oxygen, such as titanium compounds. Finally, an evaluation of mechanical properties showed promising results: low impurities and residual micro-porosity, fine and homogeneous microstructure, consistent material properties with a small scatter [11, 12]. However, there is a lack of technical and scientific literature on the machinability of such materials, since their characteristic are significantly different from their cast versions.

In order to satisfy the critical requirements fixed by automotive and aerospace industries, for the quality control of manufactured parts it is essential to consider not only dimensions and surface roughness but also form deviations as defined in standards proposed by ISO GPS (Geometrical Product Specification and Verification) [13-15]. Referring to a drilling process, two different form deviations should be analyzed: roundness and cylindricity. ISO 1101 defines roundness as the separation of two concentric circles that tightly enclose the circular section of interest, and cylindricity as the separation of two coaxial cylinders that tightly enclose the cylindrical feature of interest. By these definitions, they provide different information on the hole quality: roundness applies to cross sections, giving local information on the hole, while cylindricity applies simultaneously to the entire surface giving a global information on the hole shape. A control of circles at different cross sections allows for an estimation of both cylindricity and roundness, giving information about the form error along the whole hole depth.

In this context, the paper deals with drilling operations carried out on an EBM sintered γ-TiAl workpiece, and presents a methodology for the quality assessment of the holes, that considers dimensional and geometrical errors.

2. Experimental Setup

Drilling tests were performed on a Ti-48Al-2Cr-2Nb (atomic %) γ-TiAl block obtained via EBM. Milling investigations on this specific alloy were formerly carried out by the authors [16, 17]. The experimental setup is shown in Figure 1. The alloy's microstructure, checked prior to the cutting trials, resulted to be fully lamellar and with a limited amount of porosities. Microstructural analysis were repeated in different positions of the workpiece, and no specific variations in grain size were detected. Tests were carried out by means of a three axis HAAS VF-3BHE vertical CNC machining centre. Tungsten carbide (90% WC, 10% Co, grain size: 0.8 μm) two-fluted twisted drills provided by Zecha GmbH were applied uncoated, under conventional flood cooling lubrication.

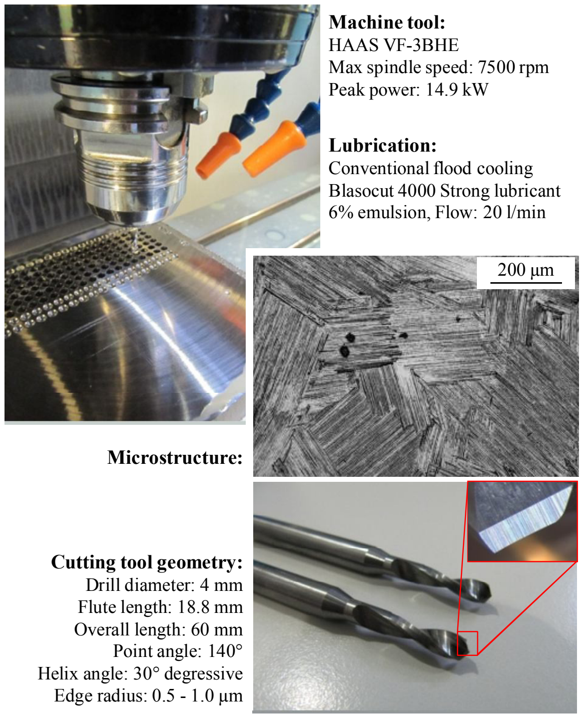

Fig. 1. Experimental setup for drilling tests.

An experimental plan [18] with a 2^2 plus central point structure was executed, in order to allow the estimation of both a first order model and the experimental error. Cutting speed v_c (15 and 30 m/min) and feed f (0.01 and 0.05 mm/rev) were selected as independent input variables (factors). Hole depth was 12 mm, and a preparatory hole was executed before each drilling operation. Tool wear was recorded at regular time steps, by means of a Dino-Lite digital microscope. Tests were interrupted when a number of holes of 280 was drilled, or when a fixed limit of 100 μm for flank wear was reached. A preliminary control of the machined surface quality was made through the evaluation of the roughness. Holes were sectioned along an axial plane, and the indicators R_a and R_t were measured in the axial direction by an Hommelwerke Tester T1000. Moreover, dimensional and geometrical tolerances were assessed