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Ball end milling of titanium TIG weld material and the effect of SiC addition – process forces and shape deviations

B. Denkena[a], A.Mücke[a]*, T. Schumacher[a], D. Langen[b], T. Grove[a], B. Bergmann[a], T. Hassel[b]

[a]*Institute of Production Engineering and Machine Tools (IFW), Leibniz Universität Hannover, An der Universität 2, 30823 Garbsen, Germany*
[b]*Institute of Materials Science, Leibniz Universität Hannover (IW), An der Universität 2, 30823 Garbsen, Germany*

Abstract

An increasing amount of blade integrated disks (Blisks) is used in turbine engines. These integrally milled components offer benefits regarding to their performance-to-weight ratio. However, in case of failure, partial replacement is not possible. The Blisk has to be replaced entirely or repaired using re-generative processes for increased sustainability. Usually, a welding process is applied for patch repair or to build up a worn tip. Afterwards, a re-contouring process such as milling is needed to restore the original shape. To determine the influence of the welding process on the process forces during subsequent ball end milling, TIG welds have been re-contoured. Moreover, to achieve grain refinement in the fusion zone and enhanced mechanical properties, SiC was added to the weld pool. Process forces during milling as well as workpiece deflections were measured. It is shown, that the welding process has a serious impact on forces and needs to be considered for a precise process planning.

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Keywords: Titanium, Milling, Welding, Repair

* Corresponding author. Tel.: +49-511-762-18270; fax: +49-511-762-5115.
E-mail address: mueke@ifw.uni-hannover.de

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1. Introduction

The repair of complex capital goods, for example an aircraft engine, is a demanding task. Not only is the interaction of production processes with the components functionality complicated but also the interaction between the regeneration processes themselves. A typical example is the repair of blade integrated disks (Blisks) made of titanium alloy, which offer benefits regarding to their performance-to-weight ratio. However, their integral design limits the reparability. In case of failure, tailored regeneration processes must be available to secure sustainability. Otherwise, the Blisk has to be replaced entirely [1, 2].

Fig. 1. Phases of repair

A typical repair process chain of blades consists of four phases, namely pre-treatment, material deposit, re-contouring and post-treatment as depicted in Fig. 1 [1, 3, 4]. During pre-treatment, the part has to be prepared for the subsequent material deposit. Depending on the repair type (blend-, crack- or patch-repair), cleaning and/or machining processes are applied. For the material deposit, welding or brazing processes are typically used. In this paper, tungsten inert gas (TIG) welding is considered. It is commonly used for welding of titanium and titanium alloys. After the material deposit, the excess material has to be removed. The removal is done via grinding or cutting. For blisk-repair, 5-axis ball end milling is often used to restore the complex shape while facing a limited accessibility because of the adjacent blades [1, 4, 5]. Afterwards, post-treatment processes such as shot peening can be used to enhance surface integrity.

To ensure adequate functional and mechanical properties of the repaired components, the local alterations induced by the welding process must be considered during re-contouring. The properties of the welded joint differ from those of the base material (BM) and strongly depend on the grain size and microstructure of the welded seam [6, 7]. In the case of TIG welding, typically coarse, columnar grains are formed within the heat affected zone (HAZ) and the fusion zone (FZ). High cooling rates cause the formation of a Widmanstätten or a martensitic α‘ type of microstructure within the FZ. This kind of microstructure generally shows increased tensile strength accompanied by decreased ductility [8]. Following the theory of Hall-Petch-strengthening, grain-refinement in the FZ can be expected to improve the mechanical properties [9].

Today, only limited knowledge exists regarding repair and the interaction of the previously described processes. Thus, this paper contributes to the interaction between the TIG welding and subsequent 5-axis ball end milling process. In particular, TIG welds have been re-contoured to determine the influence of the welding process on the process forces during subsequent ball end milling. To investigate the influence of the microstructure, conventionally welded material as well as weld material with a fine grained FZ was re-contoured.

2. Methods

In order to characterize the influence of the TIG weld repair on the subsequent ball-end milling process, bead on plate welding was carried out on Ti-6Al-4V alloy substrates. These substrates were in the mill annealed condition according to AMS 4911. To investigate the cutting forces, rectangular samples with a size of 98 mm x 83 mm x 10 mm (type 1) were prepared. Moreover, to simulate possible shape deviations during application of the repair processes to real turbine blades, samples with a size of 110 mm x 45 mm x 5 mm (type 2) were machined. A 0.5 mm deep and 5 mm wide welding groove was milled in the samples along their longitudinal axis. These grooves were filled by one pass of TIG welding with Ti-6Al-4V welding wire of 1.0 mm in diameter. The chemical composition of the substrate and filler wire is shown in Table 1. In a first series, both sample types were conventionally welded. In order to investigate the influence of the formed microstructure, in particular the grain size within the FZ, SiC powder was added to the weld pool in a second series. A SiC suspension, containing acetone and SiC particles of 2 µm average size, was sprayed on the specimens to ensure a homogeneous distribution. Acetone was selected as the diluting agent given that it evaporates rapidly after spraying, leaving only the SiC particles on the groove’s surface. This method proved successful in that the SiC powder was sufficiently adhered to the surface resisting the shielding gas flow. A layer of 1.77 mg/mm SiC was measured on the groove’s surface prior to welding. The welding process was executed in a shielding gas chamber which sustained a protective argon gas atmosphere (O_2 content < 10 ppm).