Simulation and Validation of Forming, Milling, Welding and Heat Treatment of an Alloy 718 Component

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ABSTRACT

This paper describes finite element simulations of a manufacturing process chain consisting of forming, weld preparation by milling, laser welding and stress relief heat treatment of an alloy 718 aero-engine part. The work also includes experimental validation with optical measurements of the part after each process step. Approximation and discretization errors were avoided by keeping the same mesh and constitutive model. The results show that the remaining stresses affect the subsequent manufacturing process step and therefore, simulation of the process chain is essential. The accuracy with respect to the geometry showed relatively good agreement between measurement and simulation.

KEYWORDS

Alloy 718, Finite Element Simulation, Forming, Heat Treatment, Manufacturing Chain, Welding

INTRODUCTION

Large structural components for aerospace engines increasingly demands a light weight design approach to meet global challenges of CO2 emissions by lowering fuel consumption. A light weight design can be achieved by assembling weight optimized sub parts from e.g. forgings, castings and sheet metal by welding. In order to have the best design and a good performance of the component prior to first production, then simulation design is essential. The use of computer aided engineering (CAE) tools can assist in designing the component as well as its manufacturing in order to minimize manufacturing trials and physical testing (Bossak, 1998). Simulation of manufacturing processes is a vital complementary tool in this approach to aid design as well as manufacturing engineers in decision making. In order to understand and optimize the fabrication concept the component state, in terms of e.g. deformation and residual stresses, will have to be considered.

Nickel based alloys are commonly used in the rear part of the engine due to elevated temperature. Alloy 718 is a common alloy in e.g. turbine rear cases, which are exposed to high temperatures as well as high structural loads. These components can be manufactured in different schemes e.g. castings with welded on flanges or fabricated with sub parts of shaped metal sheets, forgings, and castings etc. which are welded together. It is well recognized that residual stresses and deviation from nominal shape raise obstacles in subsequent manufacturing steps. Forming and welding operations are known to result in large residual stresses and a suitable

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stress relief heat treatment is usually resorted to relax these stresses. While it can be argued that components should be stress relieved after each operation, this increases the cost and can also lead to undesirable micro-structural changes depending upon chemistry of the structural material. For example, in the case of alloy 718, growth of δ-phase after too long or too many heat treatment cycles (~5-8) has been reported and can degrade material properties (Andersson, Sjöberg, & Hatami, 2007). Therefore, the number of heat treatments should be kept to a minimum. Thus, it is important to understand how the manufacturing history affects the final shape of the geometry and how residual stresses evolve at different steps.

The aim of this study is to develop a validated simulation model of a manufacturing process chain, see Figure 1, comprising forming, weld preparation by milling, laser-welding and stress relief heat treatment, associated with fabrication of an aerospace guide vane in alloy 718. The main focus is on the fulfilment of specifications concerning geometric tolerance. This is because the manufacturing chain affects geometric tolerances. However, the internal stress of the component needs also to be assessed. In this case the calculated deformations are verified by corresponding optical measurements. Additionally, the evolution of stresses through the manufacturing process chain is also studied. A commercial finite element (FE) software MSC.Marc is used in the simulations.

**BACKGROUND**

Earlier simulations of manufacturing processes have mostly been concentrated on just one or two stages of the entire component fabrication chain, e.g. welding and heat treatment. Makinouchi (Makinouchi, 1996) used simulation of sheet metal forming to investigate different requirements of each industry, e.g. prediction of wrinkle, surface deflection, blank geometry etc. A number of simulations of a two-step manufacturing process chain of steel components have been done (Berglund, Alberg, & Runnemalm, 2003; Cho, Lee, Moon, & Van Tyne, 2004; Lu, Wang, & Murakawa, 1999; Murakawa, Lu, & Wang, 1998; Olabi & Hashmi, 1995; Sedighi & Davoodi, 2010; Wang, Lu, & Murakawa, 1998; Zaeh, Papadakis, & Langhorst, 2008) and for titanium and aluminum component (Yang, Zhao, Gong, Jiang, & Sun, 2011). Simulation and validation of TIG welded alloy 718 plates has also been reported and shown to be in fairly good agreement with experimental data (Fisk & Lundbäck, 2012; Lundbäck, Alberg, & Henriksson, 2005). Incorporation of residual stresses and alleviation of these stresses through a stress relief heat treatment has been investigated on steel specimens (Leymonie, 1980; Ritter & McPherson, 1970) and for alloy 718 (Steffenburg-Nordenström). Simulation of manufacturing processes is mostly focused on individual steps but should be considered as elements of a system of simulations (Kreis & Hein, 2001; Tikhomirov, Rietman, Kose, & Makkink, 2005). A three-step simulation of a billet of stainless steel was done with a fictive case, but with realistic parameters, when forging, heat treating and finally cutting (Hyun & Lindgren). More recently, three step simulations spanning forming, clamping and a simplified welding procedure for automotive applications have been reported (Govik, Moshfegh, & Nilsson, 2013; Govik, Nilsson, & Moshfegh, 2012).

**Figure 1. Flow chart of the manufacturing process chain**
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