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Modelling of the electron beam welding process applied to aircraft engine components†

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1. Introduction

A thermo-mechanical model of the electron beam welding process has been developed in Morfeo (Cenaero welding software). It allows predicting the temperature evolution, the distortions and residual stresses at the end of the process. The welding of a blade on an aero engine stator has been studied.

The electron beam welding (EBW) process is extensively used for assembling titanium and other high strength components in the aircraft engine industry. For such applications, it is important to predict distortions and residual stresses after the welding process.

A transient numerical model of the electron beam welding process has been developed in the finite element code Morfeo. The modelling of the thermo-mechanical problem allows predicting the level of the residual stresses and distortions at the end of the process.

This numerical model will enable the optimisation of the welding process in order to improve the design without having to perform expensive experimental work.

2. Numerical model

The main objective in the modelling of the welding process is the prediction of the distortions and the thermal and residual stresses rather than solving the laws of the fluid mechanics in the weld pool and the keyhole. Therefore, a phenomenological approach, based on the utilisation of a power density distribution is used to model the welding beam.

In the thermal model, the 3D equivalent heat source is modelled using a superposition of an ellipsoidal and conical shape heat source with Gaussian power density distribution in order to reproduce the shape of the fusion zone [1, 2].

Because the residual stresses are directly related to the high temperature variation, its important to have a good representation of the heat flux produced by the electron beam. The parameters of the heat source are chosen such that the simulation results match experimentally measured temperatures and weld pool shape profile.

Given that the heat flux is defined in a local frame moving along the welding trajectory, an axes change has been implemented to get the heat flux values in the reference frame.

The thermal conductivity and heat capacity are considered functions of the temperature. The radiation heat loss and heat transfer with the support are also taken into account. In this welding process, there is no free convection because it takes place in a high vacuum environment, around 10^{-6} bar, to avoid the electron beam scattering with the air.

In order to avoid a numerical instability, known has the thermal shock problem, a lumped heat capacity matrix is used, as suggested in [3]. This numerical instability appears under some particular conditions when the finite element method is used to solve the transient thermal problem. It has been found that without this lumping method, the mesh in the region close to the welding zone should be highly refined to prevent numerical instabilities, leading to a prohibitive computation time and memory cost on industrial applications.

Once the temperatures are known, the resulting thermal and residual stresses are computed by a mechanical model. In Morfeo, the coupling between the thermal and mechanical calculation is staggered. The mechanical properties of the material are considered function of the temperature.

It is very important to emphasise that the greatest influence on the thermal and residual stresses is due to the variation of the yield strength as a function of the temperature [1].

3. Applications

Figure 1 shows the stator of the compressor stage of an aircraft engine, made of a titanium alloy. The blades are assembled on the stator using the electron beam welding method.

The welding of a blade on a section of the stator (illustrated **Fig. 2**) has been studied. The welding velocity is assumed constant along the trajectory. The welding trajectory is defined directly from the CAD geometry. Therefore, complex welding paths can be easily defined.

Figure 3 shows the mesh, generated with the Simmetrix library, used in the welding simulation. The mesh has been refined in the welding zone where high thermal and stress gradients are encountered. **Figure 4** shows the temperature computed by Morfeo during the EBW

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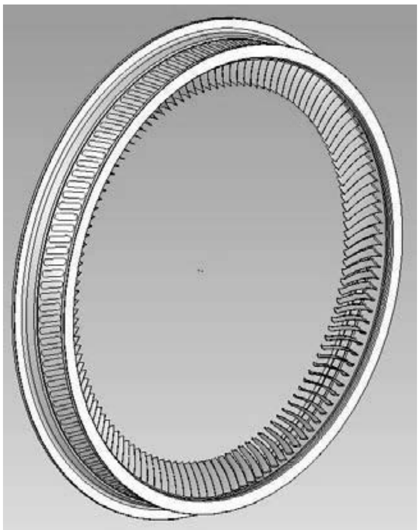

Fig. 1 Stator of the compressor stage of an aircraft engine assembled by a EBW technique.

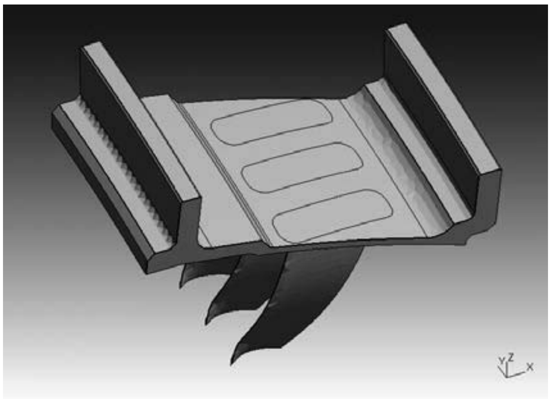

Fig. 2 Section of the stator.

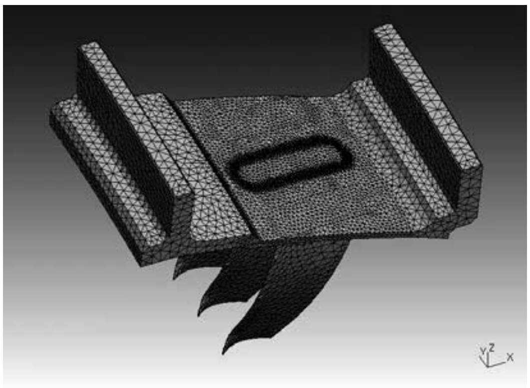

Fig. 3 Mesh of the stator section.

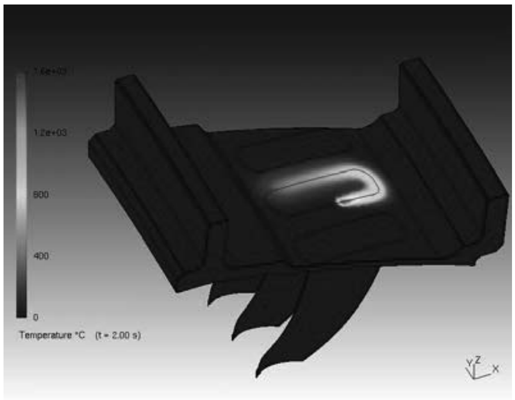

Fig. 4 Temperature field during the welding process.

process. The simulation results still need to be validated with experimental measurements.

An inverse analysis will be performed to determine accurately the heat source parameters from temperature measurements on samples.

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