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Shot peening and peen forming finite element modelling – Towards a quantitative method

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ABSTRACT

Peen forming is commonly used on aluminium alloys in the aerospace industry for wing skin shaping. Numerous analytical, numerical, and experimental studies have been made to better understand the effects of various peening parameters on the final material state and to predict deformed shapes, but conclusions were often limited to trends. The purpose of this study is therefore to develop and verify experimentally quantitative numerical tools for peen forming applications by studying the simple case of peening an Almen-sized AA-2024 aluminium strip in an Almen holder. The first step consisted in improving an existing random dynamic model by determining optimal dimensions. The AA-2024 target mechanical behaviour was characterized experimentally and a combined isotropic-kinematic hardening law was selected to model the material behaviour. The dynamic impact model and material constitutive law provided good prediction of peening-induced stresses in thick AA-2024 for two shot velocities. The sequence-sensitive aspect of the forming process was also investigated and a new shell-based finite element model was proposed. Numerical and experimental results for three shot velocities were compared to evaluate the validity of this numerical simulation method and promising agreement was observed.

1. Introduction

Peen forming is a cold-working method used to modify the shape of thin components. In this process, small particles are propelled towards a metallic surface at high velocities. Each impact creates an indentation in the material, inducing plastic stretching near the surface. Since the underlying material is not plastically deformed, compressive induced stresses are created close to the surface. These induced stresses offset the mechanical equilibrium, leading to bending and/or stretching. Useful shapes with relatively small curvatures (*i.e.* large radii) can be created by carefully controlling the peening parameters. This flexible and cost-effective method is commonly used in the aerospace industry to shape large parts like wing skins and rocket shells.

Two measurands are commonly used to evaluate the intensity and progress of peening. The first method is the determination of the saturation curve. It is created by measuring the deflections of thin strips subjected to peening to characterize a specific set of process parameters. It involves plotting the arc height of SAE 1070 steel strips (called Almen strips) peened in an Almen holder as a function of peening time. The saturation point is calculated by determining the time T for which doubling the peening duration increases arc height by exactly 10%. The measured arc height a_h^S at time T is defined as the Almen intensity. Fig. 1(a) illustrates this technique. The second measurand used is coverage: progress of shot peening is evaluated by determining the proportion of a peened area covered with indentations from impacts. Fig. 1(b) shows the concept of coverage evaluation.

In shot peening, unbalanced induced stresses create stretching and bending of the part to reach a balanced residual stress state. Unbalanced induced stresses σ_{ind} are those encountered in a fully constrained component that does not allow stretching and/or bending (VanLuchene et al., 1995). Residual stresses σ_{res} are those present in a component after the removal of external constraints and are mechanically balanced. Induced and residual stresses are related through:

$$\sigma_{ind} + \sigma_{axial} + \sigma_{bend} = \sigma_{res} \quad (1)$$

where σ_{axial} is the stress field related to stretching and σ_{bend} is the stress field related to bending (Homer and VanLuchene, 1991). For simplification purposes, σ_{axial} will be referred to as "axial stress" and σ_{bend} as "bending stress". Both of these stresses can be calculated from the forces applied by the external constraints in order to maintain the induced stresses. Residual stresses measured in a thick component can be used to estimate induced stresses since a large thickness does not allow significant bending and stretching and therefore $\sigma_{ind} \approx \sigma_{res}$ for a thick part. Fig. 2 presents graphically

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