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Potential applications of peen forming finite element modelling

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ABSTRACT

Peen forming is a versatile and flexible manufacturing process commonly used in the aerospace industry to shape wing skins and rockets panels. Development of peening parameters needed to obtain a specific component shape can be both costly and challenging due to the use of empirical methods which involve large quantities of physical experiments coupled with trial and error processing of prototype components. Many iterations are often required to get the desired shape with no guarantee that a specific component geometry can be achieved. Reliable numerical simulations could substantially reduce the time, cost and risk associated with process development. The purpose of this study is to further investigate the use of numerical tools to model the peen forming process. This work combines static and dynamic simulation techniques to predict the development of curvature on representative wing skin panels that include features such as integral stiffeners. This work illustrates the considerable potential of finite element simulations to determine the process parameters needed to produce a component design, and substantially reduce the dependence upon physical testing.

1. Introduction

Shot peening is a surface treatment performed by projecting numerous small particles at high velocity onto the surface of a metallic component. Each impacting shot plastically deforms the surface of the part. Repeated impacts lead to in-plane plastic stretching and compressive stress near the surface of the target component. The shot peening process can be separated into two distinct groups. The first, termed saturation peening, involves the complete obliteration of the surface of a component with impact dimples: this treatment is applied to improve the resistance of a component to fatigue and stress corrosion [1]. The second group, peen forming, is performed at higher impact energy and lower surface coverage and is used to shape large and thin aluminium alloy components typically found in the aerospace industry, such as wing skins or rocket panels [2,3], or to correct machining induced distortion of complex components such as ribs and spars [4]. The principle of peen forming can be explained as follows (Fig. 1). When a component is perfectly constrained during peening, surface plastic strains generate an “induced stress” profile [5]. This profile alters the mechanical equilibrium within the component. Upon removal of the constraints, the part bends and stretches. The final balanced stress profile is referred to as “residual stress”. This balancing phenomenon allows thin parts that require relatively large formed radii to be produced by the shot peening process.

While shot peening of aluminium alloys is usually performed with small ceramic or steel shots, peen forming requires larger and heavier steel shots to achieve the shaping effect (Table 1). Peen forming is a flexible process since a wide variety of shapes can be attained by a simple variation of process parameters (*e.g.* shot size, type, velocity, exposure time, area of application, etc.). Peen forming can be considered to be dieless, unlike other metal forming processes that require dedicated – single purpose – tooling to produce a specific component geometry.

Typical applications for wing skin forming involve a sequence of treatments with different parameters [10–13]. Panels are first saturation peened on all surfaces with small shots at relatively low impact velocity (energy) in order to introduce beneficial compressive stresses on all surfaces and improve fatigue life [2,5,10–12]. This operation also has the effect of elongating the part slightly, as shown in Fig. 2a. Further operations are then applied to induce three dimensional curvature in the component. Forming operations need to increase the induced stress amplitude and/or the depth subjected to compressive stresses in order to upset the bending equilibrium and induce curvature, as illustrated in Fig. 2b. This is usually done by projecting larger shots onto the surface.

Forming operations are carried out in two stages [2,10,11]. The first stage is to induce a chordwise shape into the component, whilst further local peening is performed in the second stage to

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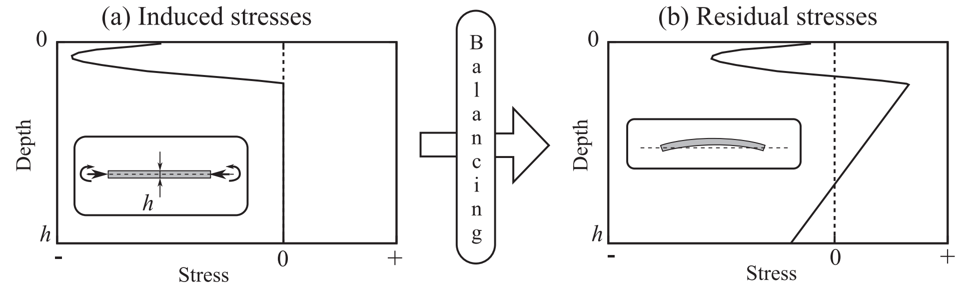

Fig. 1. Relationship between (a) a typical induced stress profile in a constrained flat part of thickness h and (b) the resulting residual stress state in the deformed part. Scales are the same for both graphs. Inserts show part shape and constraints.

Table 1
Examples of shot types used for saturation shot peening and peen forming aluminium alloy components [6,7].

Application	Designation (kg/m^3)	Material	Density	*xxx* indicates...	Example Diameter (mm)
Saturation shot peening	B*xxx*	Ceramic	3850	–	B120 [8] 0.063–0.125
Saturation shot peening	Z*xxx*	Ceramic	3850	Minimum shot diameter, in μm	Z425 [9] 0.425–0.600
Peen forming	S*xxx*	Cast steel	7800	Nominal shot diameter in 1/10,000 of an inch	S660 ≈ 1.41–2.4

induce a spanwise contour through the creation of dihedral or anhedral breaks in the chordwise contour. When peening is conducted uniformly on an unconstrained plate made of an isotropic material, the part develops a spherical shape with uniform curvature in all directions; component contours are however much more complicated. Different techniques are therefore combined to achieve the required contours:

- Different peening parameters are used on different regions of the component due to the variable stiffness and target curvatures of the component [2,13,14].
- Spherical deformation can be inhibited by peening narrow strips to develop directional curvature [2,15]. Peening parallel strips along the span direction leads to a tighter curvature along the chord direction and a smaller curvature along the span direction.
- As shown in Fig. 2b, peening both sides of a plate tends to elongate the part. Elongating the edges of a curved component can reduce spherical deformation [2,5,12,14], whilst elongating the centre of a curved component can increase the spanwise curvature and shape a "hog back" contour.
- Integral stiffeners contribute to reducing spherical deformation by introducing a larger bending stiffness along the span direction [2,13]. In addition, the surfaces of the integral stiffeners can be peened to obtain elongation and further mitigate spherical curvature or create dihedral curvatures along the span direction (saddle shape) [12,13,16,17].

In addition to out-of-plane shaping, peen forming creates in-plane displacements in the component [10,18]. As shown in Fig. 3, these phenomena are growth (elongation) and fanning (angular deformation). Even though typical growth and fanning displacements are relatively small, they must be considered for assembly of the shaped wing skin. For instance, the edges of heavily peened wing skin panels may have to be trimmed to restore the correct edge profiles and allow assembly. In addition, in extreme cases important feature locations such as spar and equipment – pumps, etc. – interfaces can move due to peening. Panel design must therefore take growth and fanning into account.

Simulating every shot impact needed to peen form a component is not practical due to the excessive calculation time [19]. Impact simulations have shown that, for a large number of impacts, shot

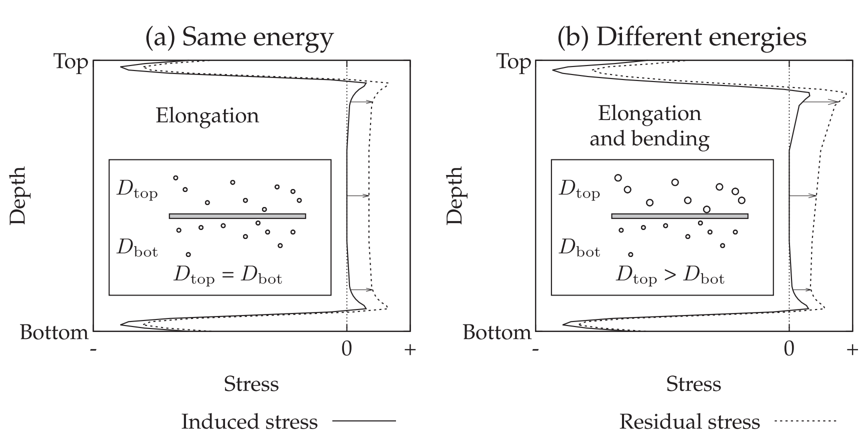

Fig. 2. Effect of peening parameters on both sides of a part on resulting elongation and curvature. Inserts illustrate peening conditions. (a) Using the same energy (same shot type and diameter D, impact velocity and impact density) on both sides, the component elongates and remains flat. (b) If the top surface is peened with a higher energy, *e.g.* larger shots with the same impact velocity, the part elongates and the top surface develops a convex curvature normal to the direction of peening.