Abstract

Thick-walled cylinders/hollow-disks find wide range of industrial applications to withstand very high pressure. Pressure vessels, gun barrels, fuel injection system in diesel engines, nuclear reactor and fastener holes are the typical examples. The cylinder may crack if the working internal pressure exceeds the yield strength of the material. The pressure carrying capacity and fatigue life of the thick-walled cylinders used for high pressure application can be significantly improved by inducing beneficial compressive residual stresses at and around the inner wall of the cylinder. This is achieved by employing a process called autofrettage, prior to their use in service condition. The most commonly employed autofrettage processes are hydraulic and swage autofrettage process. The hydraulic autofrettage is achieved by pressurizing the cylinders to an ultra-high hydraulic internal pressure. The swage autofrettage is achieved by pushing an oversized mandrel through the inside of the cylinder to plastically deform the inner wall and some portion beneath it. The autofrettage can also be achieved by detonating an explosive charge inside the vessel, which is called explosive autofrettage. All these existing processes have certain disadvantages. In order to avoid the difficulties associated with the existing methods of autofrettage, in the present thesis, a thermal autofrettage process is proposed. The proposed thermal autofrettage process is achieved by creating a radial thermal gradient across the wall thickness of a cylinder or hollow disk. The proposed thermal autofrettage process is very simple and easy to handle compared to the existing methods of autofrettage.

In this thesis, a theoretical and experimental study of the thermal autofrettage process is carried out. For the theoretical analysis, two analytical models— plane stress and generalized plane strain model have been developed. The plane stress model is applicable for the very short cylinders (thin disks) such as fastener holes and the generalized plane strain model is applicable for long cylinders such as gun barrels and pressure vessels. The models are based on the Tresca yield criterion and its associated flow rule. The strain hardening behaviour of the cylinders during autofrettage is studied. A three-dimensional finite element method (3-D FEM) modeling of the thermo-elasto-plastic stresses generated in the cylinder due to thermal gradient is also carried out in ABAQUS finite element package. The finite element results are compared with the stresses predicted by the plane stress and the generalized plane strain models. A criterion is developed for assessing the analytical models on the basis of the length to wall thickness ratio, $L/(b-a)$ of the cylinders.

An experimental setup has been developed for creating the desired temperature difference across the wall thickness of the cylinder to achieve thermal autofrettage. The experimental assessment of the residual stresses set up in the cylinders after thermal autofrettage are carried out using three different techniques—Sachs boring method, microhardness test and the measurement of opening angle as a result of cutting through the wall of the cylinders. All three experimental methods indicate the presence of beneficial compressive residual stresses at the inner wall of the thermally autofrettaged cylinders.

A comparative study of thermal and hydraulic autofrettage is also carried out. A parametric study is carried out for both thermal and hydraulic autofrettage and comparison is made. The thermal autofrettage process is also studied for the thick-walled cylinders subjected to high thermal gradient with or without pressure and is compared with the hydraulic autofrettage. Comparison shows that for cylinders subjected to high thermal gradient without pressure, the thermal autofrettage is superior to the hydraulic autofrettage. A methodology is proposed in this thesis for enhancing the pressure carrying capacity as well as the fatigue life of the thermally autofrettaged cylinder through shrink-fit. It is estimated that the pressure carrying capacity and the fatigue life of the thermally autofrettaged cylinder with shrink-fit significantly improves as compared to the corresponding thermally autofrettaged as well as non-autofrettaged single/monobloc cylinders.

The overall theoretical and experimental study of the thermal autofrettage process reveals that the process is a commercially viable and useful process. The simplicity of the process makes the process to be competitive with the existing methods of autofrettage.