INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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SHORT ABSTRACT

Autofrettage is a classical metal working technique for increasing the pressure bearing capacity, fatigue life, creep and stress-corrosion cracking resistance of thick-walled cylindrical and spherical vessels. Autofrettage is carried out by applying a load to the thick-walled cylinder or sphere that causes a partial or full plastic deformation. When the vessel is subsequently unloaded, compressive residual stresses are induced in the vicinity of the inner wall whereas tensile residual stresses are induced in the vicinity of the outer wall. On the basis of the type of load used for the plastic deformation, autofrettage can be classified into five types such as hydraulic, swage, explosive, thermal and rotational autofrettage.

Literature review indicates that hydraulic autofrettage is one of the two most popular and widely accepted type of autofrettage processes, together with swage autofrettage. However, the requirement of very high pressure makes the process costly. On the other hand, the thermal autofrettage is very simple although the achievable maximum increase in the pressure carrying capacity is limited due to the restriction on the maximum allowable temperature difference. Another detrimental feature that is common in any autofrettage processes is that the tensile residual stresses in the vicinity of the outer wall weakens the autofrettaged cylinder or sphere, a condition that is further aggravated in the presence of external surface flaws like cracks or wears as the tensile stresses causes the cracks to open up.

The focus of the thesis is the design of a special class of autofrettage processes that could be called as “thermally assisted autofrettage processes” where a conventional autofrettage process is augmented by a thermal load. The scope of the thesis is limited to hydraulic and thermal autofrettage processes. The first objective of the study is to explore the feasibility of economizing a hydraulic autofrettage process and increasing the efficacy of a thermal autofrettage by combining them in a single process. A finite element method (FEM) modeling of a combined hydraulic and thermal autofrettage of a thick cylinder was carried out by applying the hydraulic pressure and temperature gradient simultaneously using an FEM package ABAQUS® for aluminum and SS304 steel cylinders. These type of cylinders are widely used for several applications and represent two widely different sets of material properties. The aluminum has high coefficient of thermal expansion and low yield strength. On the other hand, SS304 steel has relatively low coefficient of thermal expansion and high yield strength. Moreover, for these materials, some analytical and experimental results are available in the literature, which are helpful for validating FEM model. A series of combinations of temperature difference and hydraulic pressure were explored for the two materials, for achieving the maximum increase in the pressure capacity. The results showed that the combined autofrettage can achieve desired increase in the pressure capacity of thick-walled cylinders with a relatively small autofrettage pressure.

The next objective was the design of a thermal autofrettage coupled with heat treatment. In the proposed method, the conventional thermal autofrettage of a cylinder was followed by a thermally reloading step where the outer wall was heated above the lower critical temperature to cause local austenization. The inner wall temperature was lower and was governed by the criterion that the corresponding temperature difference did not yield the cylinder. This was followed by a quenching process in which the cylinder from both the walls after which compressive residual stresses were induced in the vicinity of the inner and the outer wall. An FEM analysis was carried out considering temperature and microstructure dependent material properties of AISI 1080 steel. Phase transformation kinetics was incorporated through the user defined subroutine UMATHT in ABAQUS®. The results indicated that the technique mitigated the harmful autofrettage-induced tensile residual stresses in the vicinity of the outer wall.

In a follow up study, thermal autofrettage of thick-walled cylinder coupled with heat treatment was carried out experimentally on thick-walled cylinder made of AH36 mild steel. An experimental setup was developed to carry out the proposed thermal autofrettage process and the heat treatment procedure for inducing compressive residual stresses to the walls of a thermally autofrettaged cylinder. The cylinder subjected to the procedure was inspected for the presence of residual stresses using two approaches— one based on the measurement of microhardness and another based on the measurement of the opening angle due to a radial cut in the heat treated autofrettaged cylinder. Based on measurements taken before the autofrettage, after the thermal autofrettage and after the heat treatment of the autofrettaged specimens, the presence of residual stresses at the vicinity of the outer as well as the inner wall of the thermally autofrettaged cylinder was ascertained.

The heat treatment design of the thermally autofrettaged cylinder was also simulated for a hydraulic autofrettaged cylinder also. An FEM based analysis is carried out in ABAQUS®. The results indicated that the heat treatment design proposed for the thermally autofrettaged cylinder to induce compressive residual stresses at the outer wall was also applicable for a hydraulic autofrettaged cylinder. However, for the cylinders subjected to high percentage of autofrettage, heating of the outer wall was needed to be carried out well-below the lower critical temperature. In fact, this was an advantage in terms of energy saving and could be implemented even for cylinders subjected to a low percentage of autofrettage.

Overall, the hydraulic autofrettage process was economized by combining it with a temperature gradient due to a lower inner wall temperature. The harmful effects of the tensile residual stresses in the vicinity of the outer wall of a hydraulically or thermally autofrettaged cylinder was also mitigated by proposing a novel heat treatment procedure. This procedure was supported by experiments carried out in a thermally autofrettaged cylinder.