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Influence of manufacturing processes and their sequence of execution on fatigue life of axle house tubes in automobiles

Srivatsan Kannan [a,b,*], Sivakumar M. Srinivasan [b]

[a] *Tube Investments of India, Corporate Technology Centre, Post Bag No: 4, MTH Road, Avadi, Chennai, Tamil Nadu, India*
[b] *Department of Applied Mechanics, Indian Institute of Technology Madras, Chennai, Tamil Nadu, India*

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ABSTRACT

Axle housing tubes are used in automobiles and are subjected predominantly to bending fatigue during its service life. The fatigue life of the tubes is largely dependent on the residual stresses induced in them at the manufacturing stage. The manufacturing processes and their sequence of execution have profound influence on the nature of residual stress distribution. Induction hardening and tempering, extrusion, and turning are the manufacturing processes involved. Residual stresses induced by each of the manufacturing processes involved are studied. The influence of process sequence on residual stresses is studied by conducting experimental fatigue tests and measuring residual stresses by X-ray diffraction. Based on the studies, it is found that the manufacturing process sequence with turning as the final process step is detrimental to fatigue life, whereas the sequence with induction hardening and induction tempering as the final process step produces least tensile surface residual stress and hence improves the fatigue life.

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1. Introduction

Rear axle housing tubes cover the rear axle shafts in an automobile. The schematic of the axle housing tube assembly together with typical bending moment distribution during the vehicle movement is shown in Fig. 1. They are non-rotating members and carry the suspension seats over which the suspension springs are mounted. They are subjected to dynamic inertial loads as the vehicle moves over an uneven road surface and hence are predominantly subjected to bending during service. The fatigue life of the tube is largely dependent on the surface properties such as surface roughness and surface residual stresses. The surface properties, to a large extent, depend on the manufacturing processes that the component undergoes and the process sequence. Each of the manufacturing process has its own characteristic influence on surface properties. Manufacturing processes involved in making an axle housing tube are induction hardening and induction tempering, extrusion, and turning process.

The influence of hardening by induction heating and the effect of case depth on residual stress distribution were studied by many authors [1–3]. Coupard et al. [4] estimated the magnitude of residual stress introduced by induction heating by employing multiphysic finite element modeling. Any hardening process is followed by tempering to reduce the brittleness caused in the hardening process. Weiss [5] studied the tempering process and found that tempering reduces residual stresses depending on tempering temperature and tempering time.

* Corresponding author at: Tube Investments of India, Corporate Technology Centre, Post Bag No:4, MTH road, Avadi, Chennai, Tamil Nadu, India. Tel.: +91 9940674485; fax: +91 44 263773824.

E-mail addresses: srivatsank@tii.murugappa.com (S. Kannan), mssiva@iitm.ac.in (S.M. Srinivasan).

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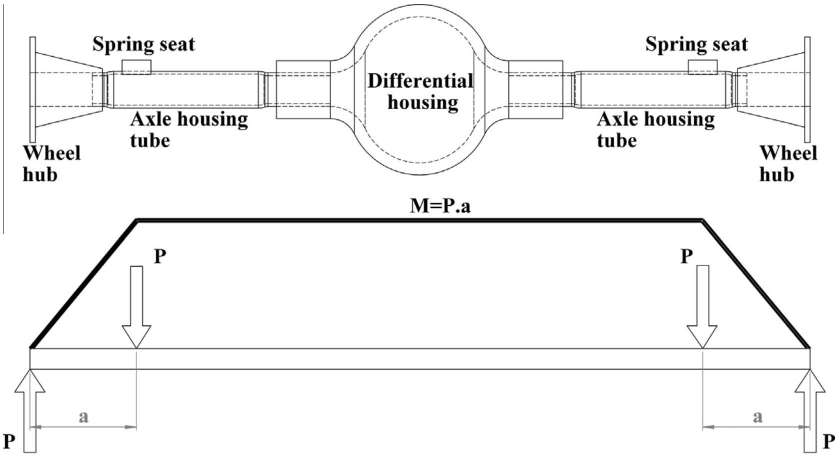

Fig. 1. Schematic of axle housing assembly with the bending moment distribution.

Hosford and Caddell [6] analyzed the extrusion of a rod by finite element analysis and observed that the magnitude of the residual stress in an extruded rod was heavily dependent on the deformation geometry of the extrusion die. Genzel et al. [7] measured the residual stress due to extrusion by X-ray diffraction technique for different reduction ratios. The measured values compare reasonably well with the predictions made using finite element analysis.

Capello [8] studied the turning operation in detail by conducting experiments with different turning parameters on steels. Based on the experimental outcome, he derived empirical equations, relating the nature and magnitude of the axial residual stress on the machined surface to the turning parameters and material properties.

Shigley [9] had proposed a practical method to estimate the fatigue life of a component. The effect of the multiaxial residual stresses on endurance limits can be taken into account in the estimation procedure using one of the widely used multiaxial fatigue criteria such as Dangvan criteria [10].

Though detailed studies have been made on the influence of different manufacturing processes on residual stress distributions as mentioned above, literature available on the influence of interaction effects between manufacturing processes when a component undergoes more than one process are scant. Polde and Dimo [11] had evaluated two manufacturing methods to make a coil spring based on residual stresses introduced by the processes and selected the one that imparted favorable residual stress distribution.

Liu and Guo [12] had studied the influence of residual stresses introduced by a metal cutting process on subsequent cutting processes when a sequence of cutting operations were performed on a metallic surface by finite element technique.

The objective of this work is to study the influence of individual manufacturing processes involved and the influence of the process sequence on surface residual stress and hence on the fatigue life of the component. A fatigue life prediction model is used to estimate the fatigue life of components under different process conditions, and the estimated results are compared with experimentally determined fatigue life. From the study, an optimal process sequence is derived that will maximize the fatigue life of axle housing tube.

2. Study of individual manufacturing processes

Individual manufacturing processes involved namely induction hardening and tempering, extrusion, and turning are studied to understand their characteristic influence on residual stress distribution before venturing into the study of the influence of their position in the process sequence on residual stress distribution. The configuration of axle housing tube is shown in Fig. 2. The profile of the component requires extrusion process at either ends of the tube to locally reduce the diameter. The schematic of the cold extrusion process and the cross-sectional geometry of the extrusion die is shown in Fig. 3. The extruded portions will be press fitted with other components in the assembly and hence requires good geometric tolerance and surface finish that cannot be met by extrusion process alone. Hence, the extruded ends are to be turned to the required dimensions. The higher strength demanded by the application necessitates a heat treatment operation, and hence, the tube is induction hardened and induction tempered.

2.1. Material characterization

The material used for axle housing tube is a low carbon steel SAE 1026. The material in strip form is roll formed and welded into tube. The roll formed and welded tube is annealed. The material properties and the microstructure in the tube after annealing are homogenous, and hence for all practical purposes, there is no differentiation between weld zone and

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