Consideration of residual stress and geometry during heat treatment to decrease shaft bending

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Abstract In automotive industry, heat treatment of components is implicitly related to distortion. This phenomenon is particularly obvious in the case of gearbox parts because of their typical geometry and precise requirements. Even if distortion can be anticipated to an extent by experience, it remains complex to comprehend. Scientific literature and industrial experience show that the whole manufacturing process chain has an influence on final heat treatment distortions. This paper presents an approach to estimate the influence of some factors on the distortion, based on the idea of a distortion potential taking into account not only geometry but also the manufacturing process history. Then the idea is developed through experiments on an industrial manufacturing process to understand the impact of residual stress due to machining on shaft bending and teeth distortion during heat treatment. Instead of being measured, residual stress is being neutralized. By comparing lots between each other, connections between gear teeth geometry and manufacturing steps before heat treatment are obtained. As a consequence, geometrical nonconformities roots can be determined more easily thanks to this diagnosis tool, and corrective actions can be applied. Secondly, the influence of product geometry on bending is experimentally considered. Moreover, metallurgical observations enable to explain the influence of workpieces geometry on shaft bending. Thanks to the obtained results, process and product recommendations to decrease shafts bending are proposed.

Keywords Heat-treatment · Shaft · Manufacturing · Distortion · Identification

1 Introduction

Heat treatment is widely used in automotive industry in order to improve mechanical properties of workpieces. Nevertheless, heat treatment has side effects such as geometrical variations on global and local scales [1]. Industrially, it means that these defects sometimes lead to increase scrap rates. In order to limit this problem, the goal of this study is to improve the understanding of distortion phenomena and so the quality of manufacturing.

Distortion is related to several causes. This study experimentally focuses on residual stress and geometry, which are two of these factors, and their influences on distortion after heat treatment are evaluated through experiments. In our case, major distortions during heat treatment are the bending
of the shafts and teeth distortions. Therefore, these geometrical parameters are considered during this study. The global aim of this project is to support both the design and the development of the manufacturing process chain. Thus, it will improve the control of gear quality.

2 State of the art

Distortion during heat treatment is a consequence of the following three major phenomena:

- Spatial and temporal heterogeneities of temperature during heating and quenching leading to heterogeneous expansion [2]
- Timing of phase transformations, for example from austenite to martensite [2]
- Decrease of yield strength when temperature increases causing stress relief by plastic deformation [2]

A high number of process parameters influences distortion. They are evaluated to more than 200 [3]. Moreover, Fig. 1 shows that distortion during heat treatment is not only due to heat treatment but also to previous manufacturing steps. As a consequence, dealing with heat treatment distortion is complex and requires taking into account the entire manufacturing process. One idea is to consider distortion after heat treatment as the result of a distortion potential gradually stored into the material all through the process [4]. Each manufacturing step contributes to the distortion potential, physically related to physical carriers. Carriers have dependencies on each other, as shown in Fig. 2 [5].

3 Objective

In this study, the manufacturing process includes cold forging, machining, and heat treatment. First, the relief of residual stress induced by forging affects distortion [6]. Then, during machining steps, turning and gear hobbing modify residual stress distribution and distortion [7]. As a consequence, residual stress can be considered in this study as a major factor of distortion [8]. Thus, among all carriers of distortion potential described in Fig. 1, this study first focuses on residual stress.

On the other hand, geometry also has a significant influence on distortion phenomena. For example, a heterogeneous geometry will generate a heterogeneous cooling and then distortions [9]. That is why this study secondly deals with the influence of geometry on distortion. The distortion is defined as the difference between geometry after a manufacturing step and geometry before this step. Geometry is measured all along the process by a coordinate-measuring machine.

As previously said, residual stress and geometry have dependencies on each other [5]. Indeed, when residual stress relieves, elastic and/or plastic deformation happen, modifying geometry of the workpiece. Microstructure also