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Study on the distortion of steel worm shafts

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ABSTRACT

This paper analyses the root causes for the distortion observed in some C45E grade steel worm shafts during the last steps of machining. Research carried out on two round bars of the steel where distortion was observed and two other ones of a batch machined without distortion were studied. Moreover, two worm shafts in the last steps of the machining process were also analysed. Residual stresses measurements revealed lower and more homogeneous distribution in the bars which do not exhibit the problem. Yield stress and ultimate tensile stress values recorded in the steel of these bars were also lower than those measured in the bars which presented the problem. Metallographic study of the first ones revealed a broken morphology of cementite in the pearlite pointing towards a material stress relieved after the rolling process, eliminating, at least partially, those stresses generated during the deformation of the bar. On the other hand, the pearlite in the steel which suffers distortion looked to be formed during the cooling process after rolling and no given posterior stress relief heat treatment. A stress relief heat treatment of the bars and/or a kinder machining are recommended.

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1. Introduction

Failure constitutes a general term which is used to imply that a part in service has become completely inoperable, still operable but incapable of satisfactorily performing its intended function, or has deteriorated seriously to the point that it has become unreliable or unsafe for continued use [1]. Nevertheless, in some cases components become inoperable even before entering in service due to unacceptable changes in their geometry during the manufacturing operations.

This situation is found in shafts which suffered a significant distortion rendering them incapable of serving their intended function or interferes with the operation of another component. Distortion failures can belong to two main types; size distortion and shape distortion. The first one refers to a change in volume (growth or shrinkage) while shape distortion is related to changes in geometrical form [2]. Distortion failures are ordinarily considered self evident but the failure analyst must go beyond the immediate cause in order to recommend proper corrective measures. It is usual to consider that deformation can occur only when the applied stress exceeds the flow stress of the material but it must be remarked that this is not the only origin of distortions.

Residual stresses can be tracked as one plausible origin of these distortions and changes in shape of the components. They are defined as those stresses which are present in a body when no external force (including gravity) or other sources of stresses such as thermal gradients are applied [3]. They may be generated or modified at every stage in the component life cycle, from original production to final disposal. They are self equilibrating, tensile residual stresses being counter-balanced by compressive residual stresses. However, during the production process this equilibrium can be broken, inducing a certain

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distortion in the body. When this distortion is large enough it precludes to obtain the desired shape and consequently the part becomes inoperable.

2. Problem

Worm-shafts were manufactured by machining C45E grade steel round bars to the final dimensions. This steel is usually supplied in the hot working condition without any additional heat treatment [4]. However, in this condition significant residual stresses can be present in the bars and induce problems during the posterior machining of the worm-shafts where an unacceptable distortion was detected when steel bars from one supplier were used. Due to this distortion it was not possible to obtain the envisaged geometry of these components which rendered to be unable to perform their labour. On the other hand, no problem was found when material from a second supplier was chosen. This fact yielded a momentary solution to the problem preventing the use of bars from the first manufacturer.

However, having only one potential supplier represented a serious risk of a lack of material when it is urgently needed. Consequently a study on the root causes of the observed distortion was performed and the conclusions reached served as guide to recommend a manufacturing route which would be followed by all the producers or improving a deficient material. This paper describes the work that was carried out and the results and conclusions which were obtained.

3. Experimental procedure

3.1. Material

As previously indicated, material chosen for the study consisted in C45E steel. Four of this steel bars were analysed; two of them belonging to the same heat where distortion problems were observed (referenced as D1 and D2) and two other ones from another supplier whose bars were satisfactorily machined to the final geometry of the worm-shafts (references ND1 and ND2). Moreover, two worm-shafts, which were in the last stage of machining, were also analysed (SF1 and SF2).

3.2. Measurement of residual stresses

X-ray diffractometry allows measuring residual stresses on the surface of the various samples. A more detailed description of this technique, their possibilities and limitations, is given in other papers [5,6]. Consequently, in this point it is only remarked the superficial character of these measures. This methodology was used for the evaluation of the residual stresses present on the surface of the four above indicated bars. Measurements were carried out on three points, sited each one at 120° from the two other to evaluate the homogeneity of the stress distribution around the circumference.

Additionally, residual stresses were also measured on the top of the threaded part of the distorted worm-shafts. The geometry of these threads precluded measuring the residual stresses on the bottom of these threaded ends. In order to obtain a more thorough evaluation of the residual stresses distribution they were also measured on the no machined end of one of these worm-shafts (this point was referenced as SF2NM).

3.3. Tensile tests

Room temperature tensile tests were performed on 12 mm diameter specimens obtained from the various bars. These specimens were machined and tested following the indications of the EN 10002 standard, measuring the values of yield stress, ultimate tensile stress, elongation and reduction of area. The idea for these tests was detecting differences in the mechanical properties of the various bars which could justify their different behaviour.

3.4. Metallographic study

Metallographic samples were obtained from the four bars and also from the two distorted worm-shafts. The last ones included to top and one bottom of each threaded end. These samples were firstly examined in the optical microscope in the unetched condition and then Nital edged to reveal the microstructure. To obtain a greater detail of the microstructure these same metallographic samples were analysed in the scanning electron microscope. Experimental work was finished measuring 10 kg Vickers hardness (HV10) at different locations of the bars (periphery, middle thickness and core) and the threads of the worm-shafts (top, middle height and bottom).

4. Results and discussion

Table 1 exhibits the results obtained on the various samples and locations as well the average value and the standard deviation of each one. These results help to find an explanation for the failure.

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