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Case study

Analysis of cracks generated in the spinning-mandrel teeth

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ABSTRACT

The spinning process, using a splined mandrel, is always prone to premature failure of the splined mandrels. Such a failure is thought to be related to the magnitude of the forming forces exerted on the mandrel by the forming rollers during the spinning process. In the present paper, the characteristic of corner cracks in the mandrel teeth (made of S7 tool steel) of a spinning process has been investigated. The rotational speed of the mandrel is about 300 rpm during spinning process and the sheet metal (*i.e.* AISI 1020) is in contact with mandrel teeth to get the mandrel shape at the end of process. During this process, the mandrel teeth eventually break away. Fractography analyses using scanning electron microscopy (SEM) clearly confirm "*fatigue*" as being the main reason for the failure.

1. Introduction

The spinning process using a splined mandrel (Fig. 1) is a very cost effective way to fabricate internally ribbed parts and has found particular application in the automotive industry [1–3]. An on-going problem with this technique is early, and unexpected, fracture of the protruding mandrel splines. During the service life of the mandrel, the tooth region experiences a significantly high number of repetitive, irregular force oscillations causing the mandrel to crack. Changes in section size, a sharp corner, or groove in the mandrel geometry all increase the chance of failure. Premature failure of the mandrel splines may result from either (i) the cyclic impact loading caused by the forming rollers or (ii) the presence of the sharp corners of the mandrel splines which are necessary to form the desired shape of internal ribs on the final part but which acts as stress concentrators.

In the present paper the premature fracture of an splined mandrel made of a shock resistance S7 tool steel (0.5C, 0.75Mn, 0.25Si, 3.25Cr, 1.40Mo), heat treated to a hardness of 57–59 RC, is assessed. S7 tool steel is an air or oil hardening tool steel that is characterized by very high impact toughness. The combination of strength and high toughness makes it a candidate for a wide variety of tooling applications. It can be used successfully for both cold and hot work applications. Also suitable for hot work tools where the operating temperature does not exceed 540 °C.

The microstructure of the mandrel contains bainite and martensite (Fig. 2). The bainite constituent contributes to fairly good toughness in this kind of tool steel (Fig. 3).

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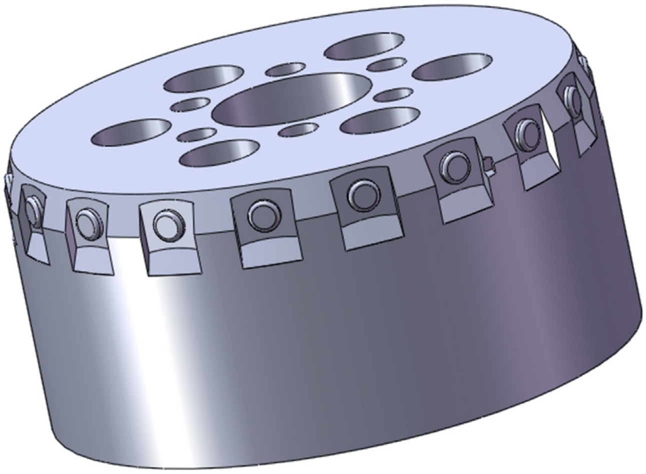

Fig. 1. Schematic representation of a splined mandrel used in the spinning process for producing internally splined components.

2. Macro-cracks in the mandrel

The majority of work materials used in the spinning operations subject the tooling to wear, mixed wear and/or chipping and cracking. The shock resistance S7 tool steel mandrel used in the present spinning operation has been observed to frequently fracture prematurely in service. Metal spinning is a rotary forming process in which the probability that the failures occur by a high-cycle fatigue mechanism is very likely [4,5]. While most tools and dies fail in a brittle manner, fatigue failures are sometimes encountered. Three basic factors that are necessary for the onset of fatigue crack growth are: (i) an applied tensile stress of sufficiently high magnitude, (ii) a large enough magnitude of $\Delta\sigma$, and (iii) a sufficiently large number of loading cycles. In the present study over the course of the spinning mandrel life, high numbers of irregular force-oscillations are applied. This is mainly due to the material displacement in and around the spline region of the rotating mandrel by forming rollers.

Visual inspection shows that flaws frequently appear at the root of splines on the side at the opposite to the direction of mandrel rotation. That is, flaws are seen on the top edge near the upper right corner of splines on the mandrel. Visual inspection and mandrel history show that cracks began to appear after about 8200 formed parts; the time for producing of each part is about 42 s. That is, the first cracks began to appear in the mandrel after about 95.5 h continuous working service.

The locations where cracking meets the surface were inspected carefully in an attempt to identify major defects in the surface which may act as the initiation sites for this cracking. The crack path at the root of a spline in the mandrel using optical

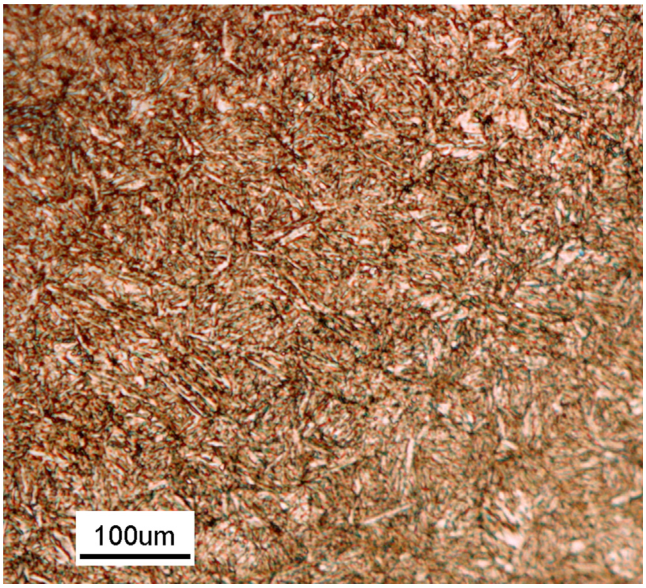

Fig. 2. The microstructure of the quenched and tempered shock resistance tool steel containing bainite and martensite phases.