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Fracture analysis of a cutting tool used in a straightening and twin bended system for coiled re-bars machine

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ABSTRACT

A company produces prefabricated stirrup cages for the reinforcement of concrete. The process consists of straightening, cutting and twin bending of coiled steel re-bars, in a custom produced machine. The punch of the cutting system failed repeatedly. Its cutting edges lose their functionality much earlier than expected. Two representative pieces were analyzed. The study included visual inspection, chemical analysis, hardness and micro-hardness measurements. Optical metallographic examination on representative samples was carried out. The fracture areas were analyzed using a scanning electron microscope (SEM) and the crack initiation and propagation were discussed. The punches failed by chipping wear mechanism due to low-cycle fatigue. Their repeating failures provoked by faulty machine design. Problem solving suggestions are proposed. In addition, alternatives related to material selection are provided in order to reduce crack susceptibility, in an economical way. Moreover, conclusions and recommendations can be useful, resulting in higher productivity of prefabricated stirrup cages.

1. Introduction

Cutting is the most frequent procedure used in tooling. Growing competition in manufacturing industry requires continuous improvement of cutting tools durability. In cold cutting processes, the main factors that influence the working life are tool design, material selection, cutting conditions and properties of the processed material.

Design is the first step in manufacturing of any engineering component. In the last decades, there are design analysis techniques available which can propose different alternatives in improving cutting productivity [1]. Consequently, designers pay particular attention to geometry configurations as cutting angles [2], cutting edge radii [3,4], or surface textures [5]. Nevertheless, cutting tools undergo diverse failures due to poor design [6–8]. It has become a usual practice to avoid failures by replacing the critical parts of the cutting system before the end of their useful lifetime [9,10]. According to the majority of the preventive maintenance processes followed, the tools are replaced when the 50–80% of their predicted working life is passed, resulting in inefficient productivity [11].

In order to perform the cutting of metals, the tools material should have adequate levels of hardness, strength, toughness and wear resistance [12]. A combination of very high wear resistance and good toughness is essential for cutting performance optimization. A wide range of tool steels are available in the corresponding market for the specific application [13]. The powder metallurgy (PM) tool steels are strongly recommended in metal cutting, offering improved mechanical properties compared to conventional ones [14–16].

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Cutting conditions have direct impact on tools efficiency. Ideal cutting conditions are defined by short cutting time, long tool life, and high cutting accuracy. In order to reduce cutting time, the procedure is carried out rapidly. Consequently, all machine parts, specially the cutting tool, are subjected to excess impact stresses. In specific instances, increasing cutting speed by 20%, the working life of the tool can decrease by 50% [17].

The properties of the processed material (e.g. annealed or hardened steel) strongly affect the cutting conditions and consequently the tool performance [18]. Processes that involve high cutting speeds during the machining of hard metals, induce high wear rates on cutting edges and increase the probability of tool breakage [19–21]. Furthermore, alternation of processed materials results in variation of the cutting conditions where different failure mechanisms could take place.

A commonly used cutting mode includes shearing. Depending on the processed material, the cutting can be carried out by normal shear blades, guillotine blades, roller disks, or nibbling [22]. For metal bars cutting, the assemblement illustrated in Fig. 1 is recommended; a lower blade (die) is nested on the main body of the machine and an upper blade (punch) moves vertically towards the bar applying shearing force. A small clearance between the edges of the upper and lower blades facilitates the fracture of the working material. During shearing, the energy is dissipated from the cutting tool, towards the processed material and the clamping device [23]. As result, the tool loading mode becomes quasi-static and the probability of breakage decreases significantly [24].

A similar cutting subassembly was applied in a straightening and twin bending CNC system. The manufacturing company produces parts used for the reinforcing of concrete. A variety of products (steel cages, steel grids, column steel covers etc.) are delivered according to customers specifications. The company designed and manufactured a machine for prefabricated stirrup cages. Raw material bars, from either concrete reinforcement or microalloyed stainless steel, with diameter variation from 4 mm to 20 mm, are used during the particular operation. The material is delivered in rolls, which are placed in a special support device (Fig. 2a). Prior to their deformation, the bars are passing through the alignment chamber for initial straightening (Fig. 2b). Upon exiting from the compartment, the raw material rounds are cut by shearing to the desired size using the specific assemblement (Fig. 2c). The final shape of the product is obtained by consecutive bending steps through deformation rollers (Fig. 2d).

The punch of the cutting system breaks down repeatedly resulting in long downtimes. The paper refers to the failure analysis of the tools. The type of the failure and its mechanism were investigated. The fracture areas were analyzed and the crack initiation and propagation were discussed. The root causes of damage were exposed and suggestions were provided, to avoid similar failure. Alternatives related to material selection are presented in order to improve the tools efficiency, in an economical way. Moreover, conclusions and recommendations can be useful in increasing productivity of prefabricated stirrup cages.

2. Experimental

Two failed punches were received for examination, associated with historical data concerning the machine design, operation and maintenance. Careful visual inspection was carried out and both pieces were photographed. Dimensional evaluation was performed and compared with the designers specifications [25]. One of the cutting tools was segmented into two parts, using a Struers LABOTOM-3 cutting machine, Denmark. The part containing the cutting surface of the punch, was cut further, and representative specimens were prepared for examination. Rockwell C hardness measurements were carried out using an Alpha Duromatic, DUROMETER D-I, Swede, on tool circumference. Vickers microhardness measurements, were performed by a Shimadzu, TYPE-M, Japan microhardness tester, on the cross section of the working surface. The applied test force was 200 gf. The tool material was identified with an OE Spectrometer Thermo ARL, USA. Metallographic examination was conducted using a Leitz METALLOVERT, Germany, reversed lenses optical microscope. The cutting edges were analyzed in a scanning electron microscope (SEM) Jeol-JSM-5600 LV, Japan and the crack initiation and propagation were discussed. Local chemical analysis of the material was performed by X-ray microanalysis using and EDX Oxford Instruments, INCA 200 software, UK spectrometer.

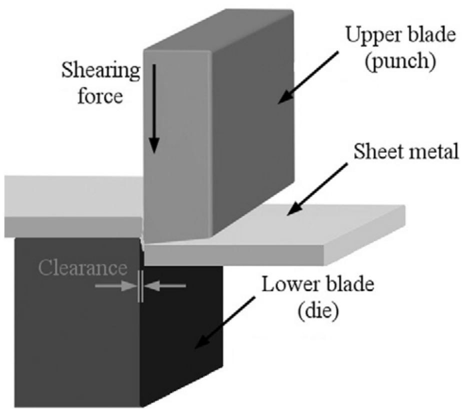

Fig. 1. 3D illustration regarding the cutting by shearing.