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CIRPJ-379; No. of Pages 8
ARTICLE IN PRESS

CIRP Journal of Manufacturing Science and Technology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

CIRP Journal of Manufacturing Science and Technology

journal homepage: www.elsevier.com/locate/cirpj

Characterisation and full-scale production testing of multifunctional surfaces for deep drawing applications

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ARTICLE INFO

Article history:
Received 8 December 2015
Received in revised form 3 July 2016
Accepted 4 July 2016

Keywords:
Surface characterisation
Metal forming
Deep drawing
Functional surfaces
Environmentally friendly lubrication
Production tests

ABSTRACT

Full-scale deep drawing tests using tools featuring multifunctional surfaces are carried out in a production environment. Multifunctional tools display regularly spaced, transversal grooves for lubricant retention obtained by hard-turning, separated by smooth bearing plateaus realized by robot assisted polishing. Advanced methods are employed to characterise the tools' surface topographies, detecting the surface features and analysing them separately according to their specific function. Four different multifunctional dies as well as two un-textured references are selected for testing. The tests are run using a non-hazardous, environmentally friendly lubricant, and the forming forces are constantly recorded. Multifunctional dies exhibit very good performances, with no galling occurrence and punch forces generally lower than the two references.

Introduction

Surfaces play an important role in governing the functional behaviour of a product [1]. In the last few decades, the progress in micro-manufacturing techniques [2] has allowed the realization of surfaces with features designed for providing particular functions: the so-called "engineered", "structured", or "textured" surfaces [3]. A large number of products of this kind have emerged during the years, capturing the interest of the CIRP community, and leading to the publication in 1999 of the renowned keynote paper by Evans and Bryan [3] in which definitions and a comprehensive classification of textured surfaces are provided. The debate went on in the following years with further contributions on surfaces' classification such as [4], or remarking the importance of proper surface characterisation [5]. In 2008, Bruzzone et al. [6] published an updated state-of-the-art of textured surfaces with a new classification of possible applications. Among all these, an important application is the possibility of improving the tribological conditions in manufacturing processes, which is an aspect of great economical relevance [7]. Texturing could, for example, be very beneficial in the sheet metal forming industry, where the prevention of the wear phenomenon called galling has great importance. Nowadays, the common practice is to apply coatings on the tool surface, and at the same time to use lubricants as chlorinated-paraffin oils, which are very high performing and typically superior to mineral oils in both mild and severe tribological conditions [8], but unfortunately contain additives harmful to human health. In recent years regulations in terms of industrial application of hazardous lubricants have become more stringent; therefore there is an interest in the industry in shifting to environmentally friendly lubricants [9]. Extensive research has been done to counter-act the loss of performance that this shift may cause, exploring also the possibility of texturing [9]. The research in this field has mainly regarded the softer workpiece in the form of indentations imparted by rollers [5], or applied artificially by an indenter after sheet production [10]. The aim of having those indentations is to trigger a phenomenon called micro-plasto-hydrodynamic lubrication (MPHL) [11]: during the forming operation the lubricant is entrapped and pressurized in the pockets, until it eventually escapes when its pressure surpasses the sealing one [12]. The escaped lubricant creates an extra-layer separating tool and workpiece resulting in a decrease of the drawing force [13]. This solution is however not fully implemented, due to the lack of understanding of the influence of the single parameters acting during the tribological process [9]. Some recent investigations have instead studied the effect of die patterning, with encouraging results in terms of reduction of friction

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http://dx.doi.org/10.1016/j.cirpj.2016.07.001
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coefficients [14] and increase of tool life [15]. In particular, it is shown in [15] how both coated and textured dies significantly improve tool life compared to polished tools. Die texturing seems therefore to represent an effective alternative to surface coating, with the advantage of not needing a subsequent vapour deposition process after the die manufacturing.

A novel die texturing technique has been developed by the Danish company Strecon A/S, which consists of hard-turning followed by robot assisted polishing (RAP) [16]. The turning operation creates a regularly patterned texture, later representing the lubricant reservoirs; whereas the RAP process removes the cusps of the turning marks leaving smooth plateau regions, producing ultimately the wanted texture. These surfaces will hereafter be referred to as "MUFU", acronym for multifunctional, since they provide both lubrication and bearing capabilities. By changing the turning tool feed rate and nose radius, or the polishing parameters, a broad range of MUFU textures can be designed and, with the aid of proper surface characterisation methods, optimized manufacturing can be achieved [17]. Preliminary tribological tests on MUFU surfaces have shown how their implementation can lead to the reduction of friction forces up to 50% compared to turned or ground surfaces in sliding contact [18]. In a recent study conducted by the authors using an off-line test equipment simulating the contact conditions during deep-drawing [19], MUFU surfaces have shown encouraging results in terms of galling prevention compared to polished tools, especially when the plateau bearing area is small.

In this paper, deep-drawing dies featuring MUFU surfaces are produced and tested in a full-scale production line, and their performance evaluated when applying an environmentally friendly lubricant, i.e. oil without harmful additives. In particular, four different MUFU dies are produced, their surfaces characterised using advance methods, and tested. Their results are compared with those of two reference dies (one polished and one PVD-coated) tested under the same conditions, and it is discussed in which way MUFU texturing can make a difference and how an optimal MUFU texture can be defined.

Die characterisation

All six dies are made of Vancron 40, a vanadium–chromium–molybdenum alloyed steel and have a curvature radius of 3.5 mm. The four MUFU dies are labelled A, B, C and D respectively, and were hard-turned before being polished to a certain extent of bearing area. The turning tool did not maintain a constant feed rate while manufacturing the dies: the feed rate was in fact changed while passing from the flat horizontal to the curvature zone (Fig. 1a). Each MUFU die is therefore characterised by two feeds. Dies A, B and D, are produced using the same feeds: 0.3 mm in the horizontal zone and 0.2 mm in the curvature. Die C has been produced respectively using the feeds 0.2 mm and 0.15 mm. Die C has therefore a higher density of narrower valleys compared to the other three. Moreover, the dies are polished to different plateau bearing areas, whose target values are: 40% for die A; 60% for die B; 50% for die C; and 30% for die D. The nominal textures of the four dies are illustrated in Fig. 2, indicating the surface features of interest, namely plateaus and valleys. The figure depicts how the change in bearing area impacts the plateau length as well as the valley depth. Therefore, the choice of the four topographies is made with the aim of covering as broad a range as possible of MUFU surfaces in relation to both their bearing and oil retention capabilities, hoping ultimately to get some indications on whether there is an optimal surface, and where it lies within this range.

The turning marks of the polished die (named Pol) are instead completely erased by the RAP machine, leaving a smooth surface. The coated die was also polished, before being PVD-coated with TiAlN, known for its wear resistance properties [20].

MUFU dies' functional characterisation procedure

The characterisation of MUFU surfaces is a quite challenging task. In [21] it is demonstrated how current standards for characterising MUFU surfaces would lead to profile distortions and unrealistic roughness parameters. A first solution to these problems is suggested in [22] and further developed in [23,24], resulting eventually in a complete procedure for advanced analysis of MUFU surfaces. This very procedure is here used for characterising the MUFU dies. The approach relies on the assumption that the different surface features have to be characterised separately depending on their functionality. Starting from the primary profile, i.e. the profile from which the large form components and the noise from the instrument have been removed, the first step is to apply an advanced filter in order to obtain an undistorted roughness profile. The advanced filter is a robust Gaussian regression filter (RGR), which is particularly efficient in the characterisation of profiles with functional features consisting of deeper pockets [25]. Unfortunately the RGR can on its turn cause profile distortions when the number of sampled points in the valleys is high [21]. In order to remove this inconvenience, a modified RGR is required which, by employing a profile upper-bound as first guess for the filtering iterations, provides eventually a reference line passing through the plateaus. A morphological filter consisting of a disc with a given radius rolled over the profile, is selected for providing the first guess. The final result is an aligned and undistorted roughness profile (Fig. 3a). The following operation is to detect the surface features, namely the plateaus and the valleys, so that they can be analysed separately. The separation method illustrated in [23] describes how to find the plateau-valley threshold and hence divide the features. The method is applied to the profile of Fig. 3a resulting in a plateau profile (Fig. 3b) and a valley profile (Fig. 3c).

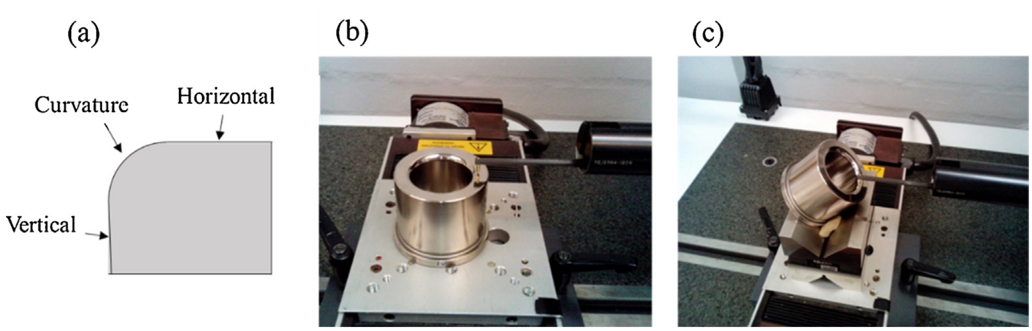

Fig. 1. Die zones (a); and measurement set-ups for horizontal (b) and curvature (c) zones.