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Off-line testing of multifunctional surfaces for metal forming applications

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ABSTRACT

In this paper, Bending-Under-Tension, an off-line test method simulating deep-drawing, is chosen for investigating the effectiveness of multifunctional (MUFU) surfaces in metal forming operations. Four different MUFU surfaces, characterized by a plateau bearing area and grooves for lubricant retention, are manufactured, together with two polished references. During the tests, surface texture is the only variable. The results show how MUFU surfaces perform better than the polished references, which produce severe galling, while MUFU surfaces with low bearing area display no clear evidence of galling. Metal-to-metal contact occurs anyway, but the strip material is pulverized and deposited onto the tool instead of cold-welding to it. The pockets create a discontinuity on the texture hindering pick-up propagation.

Introduction

Friction and wear are well-known physical phenomena occurring at surface level which cause the consumption of considerable amounts of energy (around 30% of the world energy [1]) and are associated with costs as high as 5% of the GDP of developed countries [2–4]. In mechanical systems, the occurrence of these phenomena is normally opposed by adding a lubricant layer between the contacting bodies pursuing a complete separation of the two surfaces (hydrodynamic lubrication). In many cases, though, this cannot be achieved, and asperities come into contact. The friction forces steeply increase leading to energy consumption, wear, and ultimately, failure. A possible solution to this problem is by surface texturing. In the last three decades, the progress in process technologies and control has made possible the design of surfaces with particular features, among which the creation of textured surfaces for improved tribological performances [5–7]. In metal forming, it is normally the workpiece which is considered for texturing, and pockets for trapping lubricant are realized by e.g., coining [8]. During the forming operation the workpiece, and with it, its pockets deform causing oil escape which will eventually feed the contact with extra lubrication. This phenomenon is called micro-plasto-hydrodynamic lubrication [8–12]. In the last 10 years the tool has begun to be considered for texturing as well. In [13,14] is shown that the application of dimples on cold-forging dies can result in a significant increase of the tool-life compared to the untextured case. In [15] experiments of strip drawing through converging dies display lower friction forces when grooves oriented transversally to the strip movement are applied to the dies compared to when the original polished dies are employed.

Among all the typologies of textured surfaces, multifunctional surfaces (MUFU), developed by the company Strecon A/S [16], represent a recent introduction. MUFU surfaces are produced by two consecutive processes generating a surface with bearing capabilities and the ability of providing extra-lubrication [17]. The pre-machining is a hard-turning or a hard-milling operation, which provides a regular distribution of surface features [17]. The finishing process is a Robot Assisted Polishing (RAP) operation, technique also developed by Strecon A/S. The RAP machine gradually removes the peaks of the original turned surface, yielding a surface with a certain degree of bearing area and a regular distribution of valleys apt to store lubrication. Thanks to the high control of the RAP machine, a broad variety of MUFU surfaces can be created [17]. In recent experiments carried out by the authors, MUFU surfaces have proved effective in reducing

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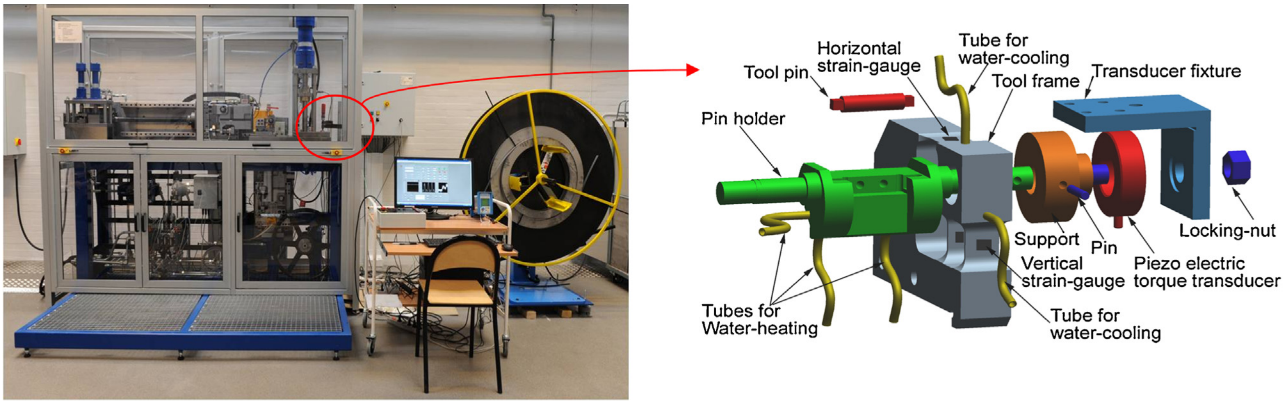

Fig. 1. Sheet-tribo-tester used for BUT tests (left) [19], highlighting the tool pin holder with embedded transducer (exploded view, right) [20].

friction in pure sliding condition, with 50% friction forces reduction compared to turned or ground surfaces [18].

In this paper, the efficacy of MUFU surfaces is evaluated when applied on tools for metal forming applications, in which, differently from the case studied in [18], the tribological contact results in the plastic deformation of the softer body. In particular, deep drawing is the metal forming operation selected for the present investigation. Due to high costs associated with testing on full-scale production equipment, Bending-Under-Tension (BUT) tests are instead performed using the sheet-tribo-tester for off-line testing presented in [19], see Fig. 1. Four different MUFU tools are investigated as well as two polished references. Throughout the tests, the tool torque is constantly measured, whose trend indicates the occurrence of galling (pick-up of workpiece material on the tool surface and subsequent scoring of the workpiece surface) [20]. The torque trends are compared and the results are discussed.

BUT test equipment and test parameters

The BUT is a well-known test method which has been employed for some 50 years (starting with the work done by [21]) in the study of the tribological conditions on the die shoulder during deep drawing operations. The die shoulder is of particular interest because it is the zone where most likely lubricant breakdown occurs [20]. The test consists basically of a plane strip drawn over a tool pin presenting the shoulder with a superimposed back tension. In the configuration chosen, the tool pin (hereafter simply 'tool') is cleaned and placed in the pin holder (see Fig. 1) and remains stationary during the test. The strip is drawn from a coil, which enables repeated testing at rates similar to production ones, allowing therefore to emulate the graduate and often slow build-up of workpiece material onto the tool surface [19]. The strip, which is lubricated continuously during the test by two felt rolls, reaches the tool pin from the bottom, it is pre-bent manually over the tool at the beginning of the test, and clamped in two claws on the horizontal and vertical axes. The front and back tensions are delivered respectively along those two axes by hydraulic cylinders, whose movements are controlled by a PLC communicating with a PC in which all main parameters are set [19]. Those are the back tension (along the vertical axis); the sliding length (or stroke length) and sliding speed, which are regulated by the horizontal axis; and the total number of strokes to be performed. The machine in operation is shown in Fig. 2 highlighting the pulling direction of the strip and the tool position. During a test, the front and back tension are recorded by means of strain gauge transducers; whereas the torque around the tool is registered by means of a calibrated piezo electric transducer with high resolution over a wide measuring range [20,22], see right-hand side of Fig. 1. The torque is demonstrated being the variable most sensitive to friction changes, and thereby the most sensitive to lubricant film breakdown and galling onset [20,23]. After a test, the tool pin is removed from the holder and a new one is inserted ready for a fresh new test session.

The tool is a 40 mm long pin which can feature shoulder radii spanning from a minimum of 1 mm to a maximum of 5 mm. At its maximum the tool is round, but for the present test campaign a radius of 3.5 mm is selected, presenting therefore two flat faces at the end of the shoulder curvature. In Fig. 3 the roughness measurement set-up of the BUT tools is shown, in which the two flat faces at the sides of the shoulder are more clearly visible.

In this framework the tests are carried out at room temperature (20 °C) and the lubricant used is Rhenus SU 166 A, where the

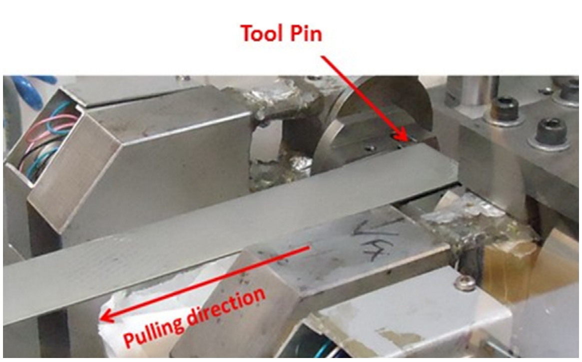

Fig. 2. Pulling direction during Bending-Under-Tension tests. The position of the tool when mounted on the machine is indicated.

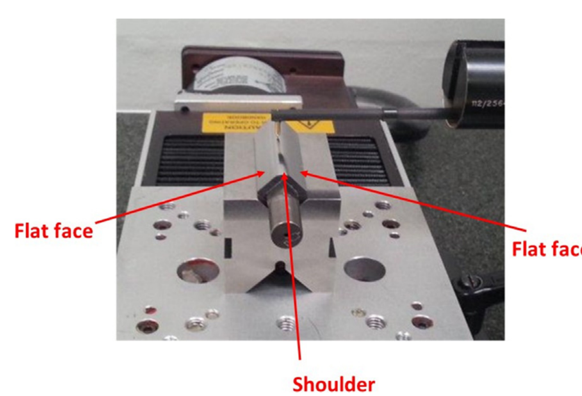

Fig. 3. Set-ups for roughness measurements on a BUT tool shoulder. The flat faces at the sides of the shoulder are also indicated.