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Technical Paper

New punch design for the elimination of punch ejection load through manipulation of the elastic strain field in the punch nose

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ABSTRACT

The extreme tribological conditions present during both the forward stroke and the punch ejection stroke of a backward cup extrusion process can adversely affect the quality of the extruded part and diminish the life of the punches. A novel punch design based on the segmentation of the extrusion punch into a main body and a nose cone insert is proposed to reduce or eliminate the pressure between the punch and work piece during the punch removal stroke. This is facilitated by manipulating the elastic strain field at the punch nose. With the aid of the finite element analysis, a parametric study on the segmented elastic punch assembly was carried out to establish optimal conditions and punch design guidelines. Experiments were carried out to determine the effectiveness of the segmented elastic punch. A significant reduction in the punch ejection load was observed along with a reduction in material pickup on the punch and galling on the surface of the part. The elastic deflection of the punch also allowed the researchers to discover that a significant amount of damage could occur during the punch ejection stroke.

1. Introduction

The dies and punches in metal forming operations can be subjected to mechanical, thermal, chemical, and tribological loads. These loads influence tool failure and the integrity of the part formed. Some of the challenges in employing forming operations to produce defect-free products are tool wear and adhesion of the deformed material to the die/punch surface, commonly referred to as galling. Galling can develop rapidly or gradually, depending on the nature of the loads exhibited at the tool/work-piece interface, tool surface roughness, mutual solubility of die-work-piece contact surfaces, etc. With repeated forming cycles, successive buildup of material on the tool can significantly shorten its life. Metal forming processes rely on lubricant to reduce the high frictional forces at the tool-work-piece interface, which in turn lessens the probability of galling. Lubricants employed by the forging industry include conversion coatings, mineral oils with a myriad of additives, and several types of solid lubricants [1,2]. For severe cold forging of steel and of aluminum products, which exhibit high interface pressure and larger surface expansion, a conversion coating is necessary to ensure that the lubricant film does not break down [3]. The zinc phosphate-based conversion coating has been the industry standard for the last 80 years for the cold forging of steel, and aluminum fluoride is a common conversion coating for the forging of aluminum products [4]. The conversion coating adheres to the billet by chemical reactions that create a pre-coat on the base metal and bonds well with various lubricants, such as metal soaps and extrusion oils. Due to its strong bond to the part surface, the conversion coating is able to prevent the lubricant from being pushed away from the part surface when subjected to high loads [5].

Although many of these lubricants have been used for decades, they either are composed of harmful materials or are produced or applied using processes that cause harm. In the case of zinc phosphate and aluminum fluoride coatings, the process of applying them to the work-piece creates a heavy metal sludge that is difficult to dispose of and poses a risk to workers [4–6]. The phosphorus, chlorine, and sulfur additives used in the various mineral oils can be difficult to dispose of and handle. This is due to harmful byproducts, such as dioxins, and the possibility of the dispersal of the additives or their byproducts into the atmosphere, which requires specialized ventilation systems in the plant [7].

The demand for environmentally friendly lubricants has prompted the development of less toxic lubricant as an alternative to conversion coatings. These lubricants include MEC HOMAT, DAIDO Aqua-Lub, and SISU Chem [6,8]. Some of these lubricants have shown to be effective, particularly for non-severe and medium forging operations. Another approach to addressing issues related to adhesive and abrasive wear of forming tools is modification of the tool surfaces to enhance tribological performance.

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Physical vapor deposition (PVD), chemical vapor deposition (CVD), and diamond-like carbon coating (DLC) are among the coating variants that have been introduced in the last decade [9–11]. For example, nitrided-type coatings have been found to perform well for dies used for aluminum alloy forging, whereas plasma nitriding and vanadium nitriding have shown to reduce galling in titanium forgings [12,13]. In a cold heading experiment to study the performance of PVD and CVD coatings of TiN on an AISI M2 tool, the CVD coated tool exhibited superior performance, whereas the PVD coating began chipping after rather few operations, leading to excessive friction. The billet material used was 34Cr4 steel. The better adherence of the CVD coating improved performance significantly [14].

Researchers have also investigated the prospect of further increasing the lubricity of tools and dies through the application of micro surface texturing [15]. In a dissertation published in 2008 by Wu the prospect of using micro grooves etched into the surface of flat dies in the cold upsetting of aluminum rings and steel strips was explored and it was determined that texturing could reduce interface friction by promoting the existence of a hydrodynamic or mixed regime lubricant film [16]. Many other researchers have presented similar results, for example in the early 2000's Neudecker et al. showed that the tribological performance of strip drawing dies could be enhanced by the micro texturing of their surface [17] and Geiger et al. reported that micro texturing could significantly increase tool life [18]. In order to create these textures researchers have traditionally turned to laser abolition techniques [19,20], but recently there has been investigation into the use of plasma [21] and laser induced plasma to machine textures onto a surface [22,23]. There have also been investigations into the use of vibration assisted machining to generate repeating texture pattern onto a surface [24].

The current study is aimed at addressing tribological issues pertaining to backward extrusion processes, with a focus on extrusion punch design. We first examine the mechanics of the backward cup extrusion process, which is characterized by a two-stroke operation cycle: a forward punch stroke to extrude the material and a backward stroke to eject the punch from the extruded part. During both the forward and backward strokes, the punch nose boundaries are subjected to high interface pressure. Thus, to prevent galling, the lubricant film should be intact during both strokes. In other words, if the lubricant is depleted (thinned out) on the internal formed walls of the cup, galling will occur as the punch is retracted from the extruded part. It should be noted that there is substantial pressure acting at the interface between the land of the punch and the cup wall during ejection. This pressure emanates from the compressive elastic strain fields on the extruded part as well as the elastic strain field from the die casing. The main goal of this study is, therefore, to establish a new class of cup extrusion punch, in which the elastic displacement field around the punch nose is manipulated such that, during the backward stroke, the punch ejection load is eliminated. Preliminary experimental results on the elastic punch were published by the authors in SME Manufacturing Letters [25]. The objectives for the current study are to (a) carry out parametric study and establish optimal conditions for the elastic punch design via numerical analysis, (b) provide a methodology that process designers could use to design elastic segmented punches, and (c) demonstrate the effectiveness of the punch through experimental examination.

2. Concept development

In order to reduce or eliminate the ejection load, the punch system should have the ability to expand during the forward stroke and contract during the backward stroke. To accomplish this, the punch is segmented into two parts: the main body and a nose insert. By introducing a conical-type insert as shown in Fig. 1a, the punch nose outer rim can be elastically stretched to OD + δ. This is possible because as the nose of the punch makes contact with the punch body on a conical taper, the forming forces will cause the nose insert to slide a small amount into the punch body. When the extrusion stroke is completed and the load on the punch drops to zero, the punch will deflect elastically back to its original shape, as depicted in Fig. 1b. If the process is designed such that the elastic deflection of the punch is greater than the spring back in the material, the punch can be pulled from the part with no resistance. This could completely eliminate damage to the part caused by the ejection of the punch.

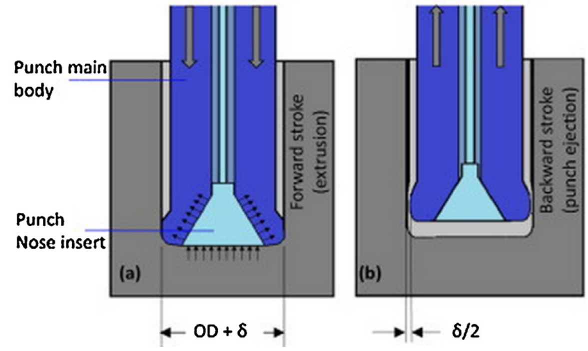

Fig. 1. Elimination of punch ejection load by manipulating elastic displacement field at the punch nose.

It is important to point out that the partitioning of the punch into two pieces has the added benefit of providing a way to supply lubricant to the area under the punch without the total ejection of the punch. For example, the nose insert can be fabricated with several micro channels that will allow the pressurized lubricant to be transported to the interface, as shown in Fig. 2a. These micro channels will allow the lubricant to travel between the punch body and the nose cone thus developing a reservoir of fluid which will refresh lubrication on the workpiece as the material slides across the punch face. The lubricant can be completely refreshed by removing the load from the punch and letting the pressurized lubricant fill in the punch/work-piece interface until the punch begins to lift slightly, as shown in Fig. 2b. After the lubrication step is completed, the forming can continue by returning the load to the punch and repeating the forming step. This permits the forming to be done incrementally, thereby preventing the depletion of lubricant on the surface of the tool and leading to better tool life, better surface quality, and reduced galling. This manuscript is, however, focused on the manipulation of the elastic strain field in the punch nose to eliminate the ejection load. Throughout this manuscript the new punch design will be referred to as "elastic punch".

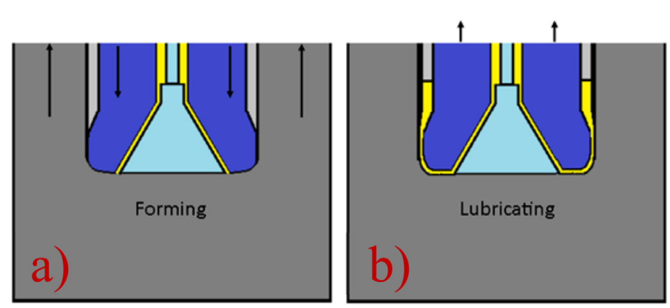

Fig. 2. Lubrication scheme utilizing the separation of the punch body and nose cone.