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Improving the punch and die wear behavior in tin coated steel stamping process

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ABSTRACT

Prestigious brands of cookies usually use metallic tins as packaging to distribute and sell their products, trying to impress the customer through the appearance of the packaging and simultaneously avoiding smashing or damaging of the cookies during logistics operations. These packages are commonly made in a tin coated (2.8 g/m^2) thin steel sheet (ARCELOR electrolytic Tin plate), which causes severe wear problems on both die and punch tool components during the stamping process at room temperature. The border of the package presents an inconsiderable deformation, despite its almost perpendicular orientation to the top surface, but this top is usually patterned, which also implies the flow of the sheet between the top and bottom die surfaces. Due to the softness of the Tin coating, it easily adheres to the die, generating premature wear and several other concerns in maintaining the required final shape of the tin lid. Lubrication would be an easy way to solve the problems referred above however, lubricated operations should be avoided as these kinds of packages are for food purposes.

This study started by identifying the main wear mechanism developed in the main surfaces of the stamping tool, promoted by the Tin coated steel sheet used in the packages. Two advanced PVD coatings (B_4C and Mo) were tested, leading to the improvement of the punch and die wear behavior under these working conditions. The transfer of Tin material from the metallic sheet to the punch and die was studied, as well as the friction coefficient of this sheet against some selected coatings, while also trying to minimize the Tin adherence to the surface of the tool. Tribological tests under medium loads were carried out in order to ascertain what kind of coating presents better wear behavior in the referred work conditions. Regarding the obtained results, some improvements will be applied to the coating structure to adjust the deposition parameters in order to go forward to industrial tests. Worn surfaces were studied by Scanning Electron Microscopy (SEM) and material transfer was analyzed by Energy Dispersive Spectroscopy (EDS).

Results obtained with some of the tested coatings confirm that it is possible to minimize the Tin transfer from the covered steel sheet to the die and punch, ensuring a longer life of these parts, decreasing the tool maintenance operations and improving the Overall Equipment Efficiency (OEE) of that stamping process.

1. Introduction

Although a huge market share of the packaging industry uses polymers, other materials can also be used that present more environmental advantages, such as the ability of being easily segregated and repeatedly recycled. The packaging for pharmaceutical products and food industries require compliance with the most demanding standards in order to avoid contaminations and preserve products. By avoiding negative environmental interactions, an increase of product shelf life during storage is achieved. Among many materials used for packages, such as glass, paper or metal, the latter usually offers all the requirements for foodstuffs. Effectively, metal packages provide two important requirements needed for these kinds of products: (1) they allow the protection against any external influence to the foodstuff during storage and transport periods via an efficient and hermitically tight container and (2) include all the necessary data about customers' information [1]. Moreover, metallic packages can assume several shapes, namely: cans for soft drinks or beer, food cans, drums and pails for cookies and others, aerosol containers for creams, tubes, caps, closures and lids (e.g. for butter containers). The manufacturing process of packages can

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involve different mechanical processes, starting usually by blanking and stamping processes, among others, which give the package its hermetic properties. However, tools used in the stamping process are permanently affected by undesirable and unpredictable wear phenomena due to friction between sheet metal (which will be deformed) and the tool, which also affects the parts' formability and surface quality [2]. Furthermore, other industries besides packaging sector, such as the automobile industry, are using increasingly Advanced High Strength Steels and Dual-Phase Steels which introduce new challenges in terms of spring-back and tool wear. Nevertheless, the steels used in the packaging industry also create tool problems through the use of thin Tin layers on sheet metal surfaces, which are relatively soft and easily increase the friction between tool and part, even in low-deep stamping. Several studies have been conducted in order to improve the stamping process and tool behavior in an attempt to minimize unproductive periods. Lubrication is commonly used to minimize friction problems and premature tool wear, but packaging clients related to the food industry are increasingly demanding the absence of such lubricants in the stamping process, even though there are lubricants with specifications suitable for the food sector. In the last decade, the most appropriate way to improve the contact between punches, dies and parts has been the use of thin coatings on the tool surfaces, in an effort to minimize friction and wear [3]. Depending on the type of sheet metal used and working conditions, several coatings have been tested using different contact situations and manufacturing parameters.

Bressan et al. [4] studied an Al_2O_3 coating obtained by MOCVD (Metal Organic Chemical Vapor Deposition) in three different steel substrates usually used in the stamping tools industry, namely AISI M2, D6 and AISI 52100 steels. Using pin-on-disc tests to evaluate the wear resistance, the authors concluded that nitrided M2 and D6 steels coated with Al_2O_3 presented the best performance in terms of wear resistance for cold work stamping tools. Vera et al. [5] also tested three different steel substrates (4320 steel, 8620 steel and 4140 steel) provided with CrN, TiN and WC/C PVD (Physical Vapor Deposition) coatings, in order to evaluate the friction coefficient and wear rate under dry contact and room temperature conditions. Authors found that the WC/C coating presented the best wear resistance performance and the most coherent friction results when two different normal loads were used. In turn, Clarysse et al. [6] studied three different coatings obtained by PVD processes: (1) the conventional CrN, (2) a well-established coating with the commercial brand Balinit C (WC/C), (3) and a new-generation TiN/MoST composite coating. Regarding the laboratory tests carried out, the worst wear behavior was exhibited by CrN, and the best performance was achieved by the WC/C coating. Different configurations of this coating were used in order to explore its capacities, and it was found that the composite DLC + WC/C system is what performs better when compared with other WC/C systems, such as triplex WC/C or pure WC/C coatings. However, the triplex WC/C system also showed promising results. Also, Ghiotti & Bruschi [7] studied DLC behavior in an attempt to improve both abrasive and adhesive wear in forming tools and compared it with three other well-known coatings (CrN + DLC, CrN and TiAlN) obtained by PVD process. In this case, dry and lubricated tests were carried out, which allows for the evaluation of possible behavioral differences depending on the contact conditions. Pin-on-disk tests were also used to characterize the coating behavior, and scratch-tests were utilized to evaluate the coating adhesion to the substrate, keeping in mind that this property is one of the most important to ensure the desired results in terms of wear resistance. Effectively, considering the four coatings tested, CrN + DLC presented the best wear resistance performance, while TiAlN showed the worst one. It is important to note the excellent friction behavior of the DLC coating in dry contact conditions. With regard to stamping applications, Zeng et al. [8] tested CrTiN, multilayered TiN/NbN films and multilayered C-composite coatings deposited onto SKH51 steel punches using an unbalanced PVD reactor. The results obtained allowed them to conclude that all the coatings used enabled a drastic increase in wear resistance and stamping performance, but CrTiN coatings presented exceptional results due to their high hardness, very good adhesion between substrate and films and adequate friction coefficient. Podgornik et al. [9] conducted tests to evaluate the improvements achieved through the application of hard coatings by PVD technique in tools for blanking and piercing processes, while also analyzing the friction regarding stamping operations. Results obtained showed that hard coatings almost always improve the wear resistance and friction, even when soft steel is being used as substrate. However, substrate preparation and a very good adhesion between coatings and substrate are determinant. Furthermore, regarding stamping operations, the same authors found that even the use of low friction coatings such as DLC in dry contact conditions lead to an increase in the critical stamping force, which lead to tool failure. They also concluded that blanking and piercing operations are not feasible without lubricant, despite the good results both in terms of wear resistance and friction coefficient obtained in the stamping process. In this study, AlCrN, TiCN and Me-DLC commercial coatings deposited by PVD technique were analyzed.

Regarding the stamping process performed at elevated temperatures (hot stamping), the previous problems are magnified and wear is more severe. In this way, some authors have carried out some studies in order to improve the wear behavior by the application of different coatings (AlCrN, AlSi, CrN, Zn) with interesting results [10–12].

Komarov et al. [13] studied the steel substrate pre-hardening effect on TiN and TiAlN coatings deposited in different treatment conditions. These authors found that nitrocarburization improved both microhardness (7 times) and working surface wear resistance (2.3 times), as well as the composite coating resilience (4.5 times), allowing to predict that it is possible to reduce the coating thickness without loss of film performance. The authors also found that nitrocarburization clearly improves both coating toughness and adhesion between substrate and coating.

Due to the need of assessing the frictional forces between the coatings and respective counter-body, many authors are selecting the pin-on-disc configuration as the best way to get results in order to characterize the new coatings developed. Moreover, pin-on-disc configuration allows to create the necessary conditions to carry out tests under severe conditions, such as elevated temperatures. However, it is well-known that the contact between the pin and the disc are not suitable for replicating the tribo-contact usually present in the tools during the stamping process.

Many other studies have been carried out in order to improve the stamping process, as well as the friction coefficient between tool and sheet metal to be worked and the punch and die wear resistance [14–17]. In these studies, new coatings have been tested in order to overcome Tin adhesion to stamping tools and prevent premature tool failure on cookie drums' low-deep stamping process. Indeed, many problems have been felt in the industrial stamping process of metallic cookie packages, where friction between the tinplate and the tool steel have left clear marks of wear and tin transfer. Thus, novel solutions need to be studied in order to overcome the friction and wear between the tool surface and the sheet metal to be worked. In this way, the coatings previously studied did not show properties good enough to solve the problems referred. B_4C and Mo films are possible solutions that can drastically decrease these problems due to their low friction coefficient and good metallurgical compatibility with tin on sheet metal surface. Laboratorial studies have been carried out in order to try to establish a correlation between tribological tests and industrial behavior.