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A new test method for measuring the galling resistance between metal powders and die tool materials in powder compaction

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ABSTRACT

The friction characteristics and galling resistance between metal powder and die tool material in metal powder compaction is of outmost importance since they will influence the porosity and surface quality of the green body and consequently the porosity, tolerances and surface quality of the final sintered product. In the present study, a new test method for evaluating the tribological performance of die tool materials aimed for powder compaction is presented. The test method is based on controlled scratch testing using a commercial scratch tester but instead of the commonly used Rockwell C diamond stylus a sample holder with a small green body of compacted powder particles is drawn over the surface in a well controlled multi pass linear reciprocating sliding contact. The capability of the test method was evaluated for different types of tool materials including two PVD coatings in contact with different types of metal powders to determine the friction characteristics and the adhesion and material transfer tendency at the sliding interface. Post-test examination of the tool surfaces using FEG-SEM and EDS were performed in order to evaluate the mechanisms controlling the friction behavior and the material transfer tendency. The results show that the proposed test is a simple and fast method to obtain relevant data regarding the friction and galling characteristics of die tool materials in metal powder compaction. The mechanisms prevailing at the green body/die tool material interface, e.g. cold welding, can easily be monitored by the friction and acoustic emission signals. Of the die tool materials investigated the low friction PVD a-C:Cr coating displayed the lowest friction and highest galling resistance.

1. Introduction

Die compaction of metal powder is a processing technique widely used in the industry. The possibility to produce near-net-shape components that need no or very little post-machining is the main advantage compared to other production techniques and makes it possible to save both time and money when components are produced in large numbers. However, powder metallurgy (PM) components produced by die pressing and sintering contain some residual porosity, typically in the range of 5%, which will limit the performance in highly loaded applications especially when the components are exposed to cyclic loading which may result in fatigue [1].

A natural step to further increase the green density and simplify the sintering process is to reduce the amount of internal lubricant in the powder since the volume fraction of an organic lubricant cannot be filled with metal powder. However, this will significantly increase the adhesive contact and thus the friction between the die and the powder/green (non sintered) body during the powder compaction process and as a result material transfer from the softer metal powder to the harder tool surfaces, causing galling, may occur. As a result, the compaction and ejection forces as well as the wear rate of the die and punch surfaces will increase. Also, an increase in friction will decrease the transmitted pressure and consequently the possibility to reach high and homogeneous green body densities is limited. Besides, the surface quality of the green compacts may be reduced due to an increased number of scratches and wear marks. Thus, today's tool materials optimized for powder compaction processes must not only display a high compressive strength, a high wear resistance and a high resistance to cracking and chipping but also intrinsic low friction properties and a low tendency to material pick-up in order to increase the galling resistance. Alternatively, the tool material can be coated by a low friction coating using e.g. CVD and PVD. Consequently, there is a great need for both accurate friction data for specific metal powder/die tool material combinations as well as a better overall understanding of the friction mechanisms prevailing during the powder compaction cycle.

The most relevant techniques for measuring the friction between powder and the tool surfaces in powder compaction

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were recently reviewed by Korachkin et al. [2]. They concluded that there is no single universally accepted technique for measuring friction between powder and the tool surfaces in powder compaction processing, but that essentially two approaches are followed: direct and indirect measurement techniques, respectively [3–8]. The direct measurement techniques involve the measurement of the shear force during the sliding of a compact against a target surface which represents the tooling. The ratio of the shear and normal forces then gives the friction coefficient. The equipment used for direct friction measurement includes the shear plate apparatus (in linear and rotational configuration) and the pin on disc machine. In the indirect approach, the friction coefficient is calculated from a die compaction experiment, where the equipment is instrumented so that the top and bottom axial stresses and also the radial stresses are known. The friction, which prevents a complete transmission of load from the top punch to the bottom punch, can then be quantified and the friction coefficient is derived.

In the present paper, a new direct measurement technique for evaluating the tribological conditions in powder compaction has been evaluated. The method is based on controlled scratch testing using a commercial scratch tester but instead of the commonly used Rockwell C diamond stylus a sample holder with a small green body of compacted powder particles is drawn over the surface in a well controlled multi pass linear reciprocating sliding contact. The paper will also present data regarding the friction characteristics and material transfer tendency between metal powders and some potential die materials including a conventional high alloyed ingot cast tool steel, a nitrogen alloyed PM tool steel, a cemented carbide grade and two different PVD-coatings. In the study post test scanning electron microscopy and energy dispersive X-ray spectroscopy was used to analyze the tribological contact between the material combinations investigated.

2. Experimental procedures

2.1. Materials

Three different die tool materials, a conventional high alloyed ingot cast steel grade, Sverker 21 (AISI D2, chemical composition in wt.%: 1.55 C, 0.30 Si, 0.80 V, 11.80 Cr, 0.80 Mo, bal. Fe, hardness 700 $HV_{0.05}$), a PM steel grade, Vancron 40 (chemical composition in wt.%: 1.10 C, 1.80 N, 0.50 Si, 9.80 V, 4.50 Cr, 3.20 Mo, 3.70 W, bal. Fe, hardness 750 $HV_{0.05}$), and a fine grained cemented carbide grade (ISO K30, 89.6 wt.% WC, 10 wt.% Co, 0.4 wt.% Cr, hardness 1650 $HV_{0.05}$), were included in the tests. Besides, two different commercial PVD coatings, TriboBond 44 (a-C:Cr), i.e. a DLC-type coating contains a small amount of Cr (2–4 at.%) and Ionbond T7 ($Al_{0.5}Ti_{0.5}N$), deposited on the PM tool steel were included in the tests. The microstructures of the steel grades in the hardened and tempered condition consist of a martensitic matrix with a hard phase consisting of relatively large M_7C_3 carbides (Sverker 21) and fine M_6C carbides/MN nitrides (Vancron 40), respectively. The size of the carbide particles are up to 50–100 μm in the ingot cast steel, around 1 μm for the carbides in the PM steel and around 0.7 μm for the nitride particles in the PM steel. The microstructure of the cemented carbide grade consists of tungsten carbide grains, size 1 μm, in a cobalt binder. The tool material samples were polished to a mirror like finish (Ra in the range 20–50 nm) using 1 μm diamond in the last step. Also, the coatings were post-treated by polishing in order to remove macro particles (droplets) from the surface thus improving the tribological performance of the coatings.

Two different metal powders, a water atomized plain iron powder (Höganäs ASC 100.29) and a water atomized iron powder pre-alloyed with 3% Cr and 0.5% Mo (Höganäs Astaloy CRM), were included in the tests, see Fig. 1. ASC 100.29 is an iron powder with very high purity and compressibility while Astaloy CRM is a pre-alloyed iron powder exhibiting an excellent hardenability and good compressibility. Both powders were tested without internal lubricant and in the particle size range 75–105 μm.

2.2. Tribological evaluation

The material transfer tendency between the metal powders and the tool steels was evaluated using a scratch tester (CSM Instruments Revetest®), see Fig. 2a, but instead of the Rockwell C diamond stylus commonly used in scratch adhesion experiments a custom manufactured sample holder of aluminum was used, see Fig. 2b. Prior to the test, the powder green body to be tested was processed and attached to the circular (ϕ = 3 mm) end surface of the sample holder. The green body was obtained by pouring a small amount of the particles (approximately 0.5 ml) into a mould after which they were simultaneously compressed and pressed into the end surface of the aluminum sample holder by simply hitting a steel rod attached to the sample holder by a small hammer. This results in the formation of a thin, approximately 0.5 mm, green body disc on the sample holder, see Fig. 3. In order to improve the adhesion of the green body to the aluminum sample holder the circular end surface was roughened using 120 mesh SiC paper and cleaned immediately before compacting the powder to the end surface. The friction characteristics and material transfer tendencies of the different sliding couples were evaluated during a multi pass linear reciprocating contact using a normal load of 50 N, a sliding velocity of 20 mm/min and a sliding distance of 20 mm. The tests were run for 10 passes after which a steady-state friction coefficient was obtained. Before testing, the die tool material samples were ultrasonically cleaned in acetone and ethanol in order to ensure that no contaminants on the sample surface would affect the friction.

All tests were performed in controlled room temperature (20–22 °C) and relative humidity (30–35%) and repeated three times. After each test the tip of the sample holder as well as the test sample were studied using optical microscopy in order to verify that no aluminum from the sample holder had been in contact with the test sample during the test. It should be noted that no internal or external lubrication was used in the test.

3. Results

Fig. 4 shows the friction characteristics of the ASC 100.29/Sverker 21 couple investigated. All couples display a similar appearance, i.e. a relatively low initial friction coefficient which increases with increasing sliding distance and increasing number of passes until a steady-state friction coefficient is obtained after 8–10 passes. Table 1 summarizes the results obtained for the sliding couples investigated. When comparing the different tool steels it can be seen that the PM grade shows a significantly lower friction coefficient as compared with the ingot cast grade especially in sliding contact with the ASC 100.29 powder. Of the PVD coatings investigated the (a-C:Cr) coating shows the lowest friction coefficient with a steady-state friction coefficient around 0.30. Finally, the cemented carbide grade display a friction coefficient similar to that displayed by the ($Al_{0.5}Ti_{0.5}N$), coating, i.e. a steady-state friction coefficient around 0.50. The scatter in the friction coefficients presented in Table 1 is typically less than 10%.

Fig. 5 shows the contact surface of Sverker 21 and Vancron 40 after 10 passes sliding contact with the ASC 100.29 powder. As can be seen the surface of Sverker 21 is to a large extent covered by adhered powder material resulting in a transfer layer composed of relatively small powder fragments. In contrast the surface of Vancron 40 shows a very small tendency to material pick-up and the carbides and nitrides present in the microstructure are still visi-