The Effect of Sliding Wear on Die Tools and its Prevention

Submitted by

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Abstract

In this study, the behavior and prevention of sliding wear along with its impact on tool wear is investigated. Sliding wear is one of the dominant types of tool wear which affects the quality of tool performance and results in premature product failure. Understanding sliding wear phenomenon will help minimize the tool wear it causes and thereby improving the quality of the tool and thus the quality of the product. This paper analyzes the studies on sliding wear mechanism and its effect on tool wear, specifically cushion pins and sleeves. Some of the factors affecting sliding wear include mechanical properties, microstructure, as well as lubrication and surface coatings of the material. In terms of sleeves, increasing hardness and toughness of the steel increases wear resistance of the material and reduces wear between the pins and the sleeves. Making appropriate changes to the design of the cushion pins and sleeves as well as changing the materials to increase material hardness increases wear resistance of the pins and sleeves. Adding lubrication and surface coating to the pin material further reduces sliding wear between the pins and the binder.

Current Research

In sheet metal stamping, die tool wear is a serious and common problem caused by extreme stresses and loads which the tools must bear during stamping of parts. Tool wear occurs due to friction caused by the contact between the tool surface and sheet metal. One study cited that tool damage such as galling, chipping, and cracking occurs due to the frictional resistance between the sheet metal and the tool surface in the cold stamping process [1]. The stamping pressure on the tool surface owing to the high strength of the sheet metal causes damage and wear to the die tools and in turn, affects product quality.

Research over the past years focusing on the wear mechanisms of die tools have found that some factors affecting tool wear include load, temperature, sliding speed, and materials of the contacting surfaces. One such study investigating the effect of sliding speed on wear behavior of steel found that adhesive wear was dominant at the tool steel surface and the wear increased as the sliding speed increased due to frictional heating between the contacting surfaces. It was also shown that although adhesive wear is dominant at all sliding speeds, it was sensitive to sliding speeds at low speed, with increased wear at low speed conditions, but was relatively insensitive to speed at higher speed conditions. The wear rate increased as the sliding speed increased for higher load, thereby concluding that sliding speed and load both impact the wear behavior of tool steel [2].

Another factor that affects tool wear is the material of the contacting surfaces. A study on wear resistance of tool steel cited that high wear resistance of tool steels can be accomplished by increasing the hardness and toughness of the material [3]. To improve wear resistance of die tools, high percentages of alloying elements such as chromium, molybdenum, vanadium, and tungsten are added to the steel along with a high carbon content in order to form carbides. However, high alloying decreases toughness and high carbide levels lead to abrasive wear of the tools. This can be reduced by using alloys manufactured with powder metallurgy, which provides the tool steel material with high impact toughness as well as high hardness necessary to combat wear [4], [5]. In terms of tool material, tool steel is known to improve wear resistance of the die tools. Tool steels are well known for the high content of carbon and alloying elements including tungsten, molybdenum, vanadium, chromium, cobalt and nickel. These elements with a combination of high carbon content make tool steel very hard, resistant to wear, tough, non-reactive to local overheating, and dimensionally stable during hardening and tempering [6].

Apart from the sliding speed and the material of the contacting surfaces, one other parameter that affects tool life is the blanking clearance. Selecting the optimum clearance is crucial in prolonging the tool life as well as better product quality by minimizing tool wear. A study analyzing the influence of blanking clearance on wear of the punch concluded that the size of blanking clearance clearly affected the intensity of punch edge wear. The results showed that the punch edge and face wear increased as the clearance increased. In order to improve tool wear, the clearance must be selected based on the type of material being used for blanking [7].

Most research studies focus on tool wear in general but it is important to understand the sliding wear mechanism behind tool wear. One of the tool components that needs to be looked at is the wear of cushion pins and sleeves. The function of cushion pins is to provide consistent force on all parts of the blank during the stamping process and wear to these pins or the sleeves they go into can result in premature part failure. This project studies the mechanism of sliding wear and its effects on tool wear, along with the ways to improve this type of wear.

Introduction

Sliding wear is one of the main types of wear causing tool damage in sheet metal stamping. This project studies the sliding wear mechanism and its effect on tool wear to better understand the impact of this type of wear between sliding tool components, specifically cushion pins and sleeves. Ways to prevent sliding wear are also determined and analyzed in order to increase wear resistance of die tools. Reducing sliding wear is necessary in order to prevent premature part failure and improve tool quality and prolong tool life, resulting in better product quality. The aim of this paper was to investigate the sliding wear mechanism and to analyze its effect on tool wear. The aim was to investigate the mechanism of sliding wear as two surfaces come in contact and rub against each other. The effect of this type of wear on tool wear was also analyzed in order to better understand the damage sliding wear causes to tools, resulting in tool failure.

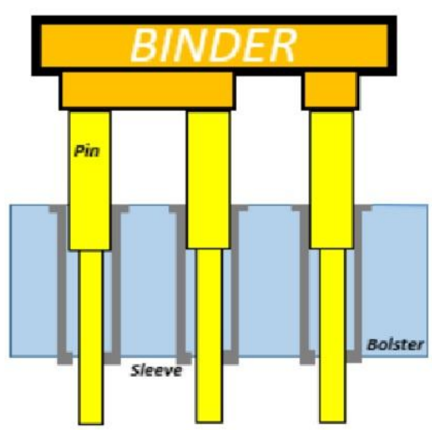

Figure 1: Pin and sleeve configuration in the press

Figure 1 above shows the configuration of the problem area of the die tools that are being considered for this study. During sheet metal stamping, the role of the cushion pins is to provide controlled and balanced force to the binder which fixes the sheet metal between the upper die and the binder. In terms of cushion pins and sleeves, as the die comes down and places force down on the binder, that force is transferred vertically down to the pins. However, since the binder moves horizontally, due to the friction between the pins and the binder, the pins move with the binder causing horizontal load on the pins. This in turn damages the sleeves as the pins slide against them during each stroke. Once the phenomenon of sliding wear was understood, ways were determined to reduce sliding wear of die tools. Wear causes loss in material and precision of die tools and therefore, increasing wear resistance of tools would decrease sliding wear between contacting surfaces and improve tool quality, resulting in longer tool life and better product quality. Reducing wear on the cushion pins and sleeves would also protect the bolster as mostly, the sleeves are pressed-fit into the bolster and they need to be machined in order to be taken out. Also, the bolster starts wearing out after the top portion of the sleeve is worn out, therefore reducing wear on the sleeves would also protect the bolster. Another purpose of this study was to suggest an experimental technique to evaluate the new proposed materials for the die cushion pins and sleeves. An experimental procedure would enable the selected materials to be evaluated for reduced tool wear, which would result in better tool quality.

Methodology

Steel is the material that was considered to study the wear behavior in terms of sliding wear. With regards to tools, stamping die tools, specifically cushion pins and sleeves were considered for study of the wear mechanism of tools and methods to reduce tool wear. The mechanism of sliding wear was investigated by researching current studies on sliding wear. The results of current peer-reviewed research investigating sliding wear of steel on steel was analyzed to conclude the parameters that affect sliding wear. Research on the effect of sliding wear on die tools was then analyzed by examining the results of scholarly studies conducted on the sliding wear behavior of die tools. Trade journals on stamping tools were studied to figure out variables that affect tool wear. The outcomes of these works along with the information collected from the trade journals was then compiled together to conclude the parameters that influence sliding wear on die tools.

Further scholarly research on wear behavior of steel on steel was conducted to analyze the factors that increase wear resistance of the material, which included material properties such as hardness and toughness. Peer-reviewed studies on wear behavior of stamping tools were reviewed to understand the sliding wear mechanism of tools and ways to reduce tool wear. The findings of the research from wear behavior of steel as well as studies on tool wear were then combined to determine parameters and choose a material that will increase wear resistance of steel and reduce tool wear of cushion pins and sleeves. Harder material such as tool steel was used for the sleeve material to ensure high wear resistance. Surface coatings were researched for the top portion of the pins to reduce friction between the pins and the binder that will also withstand the high load. Tungsten disulfide coating was selected for the top of the pin puck in order to reduce friction between the pins and the binder. Also, numerical wear analysis calculations using Archard's wear model and wear simulations using Ansys were conducted to confirm that the newly selected pin and sleeve materials do in fact reduce wear when compared to the old materials. Furthermore, a wear analysis test was suggested in order to test the wear behavior of the proposed materials for the cushion pins and sleeves. Pin on disk test was recommended as an experimental technique to use for wear analysis of the suggested tool materials.

Results and Discussion

The sliding wear mechanism and its effect on tool wear were analyzed in order to reduce wear between cushion pins and sleeves. Research was conducted to better understand the sliding wear mechanism and ways this wear can be reduced. When considering the effect of material hardness on the friction and wear, it was found that the sliding contact wear is affected by applied load, distance traveled, and material hardness. The study found that the wear decreases as the material hardness is increased [8]. In terms of materials with the same hardness, it was found that microstructure is important to determine wear behavior. A study found that the pearlitic microstructure showed the best wear resistance, followed by the ferritic-pearlitic microstructure and finally by the globular cementite embedded in a ferritic matrix [9]. Since this paper investigates die tool materials of different hardnesses, microstructure can be ignored. In one of the studies investigating die wear for automobile panel stamping, it was found that the area of contact is crucial in sliding wear as the two surfaces slide past one another. Therefore, material plays a key role in determining the amount of wear under sliding conditions. The study found that increasing the material hardness reduced the wear on the die, thereby concluding that material hardness has a direct correlation with increasing wear resistance of the tool [10].

When studying sliding wear and selecting materials for sliding wear prevention, it is important to also understand the type of wear that is more prominent. With sliding wear, adhesive wear is dominant. Adhesive tool wear occurs when soft, adhesive work materials, such as aluminum, copper, stainless steels, and low-carbon steels, are used. Conditions that increase adhesive wear are high friction and heavy loading [11]. Since adhesive wear is the type of wear that is also prominent in cushion pins and sleeves, it is important to understand mechanisms that reduce this type of wear in order to select optimal material. To reduce adhesive wear under sliding conditions, the material properties include low coefficient of friction, high yield strength, high carbide count in the matrix, and high ductility. These properties also relate to the hardness and toughness of the material [11]. Therefore, the materials selected for the cushion pins and sleeves had higher hardness and ductility to be able to withstand high load and also prevent wear.

In terms of the cushion pins and sleeves that are investigated in this paper, current pin and sleeve material were replaced in order to reduce wear between the pins and the sleeves. For the specific problem investigated in this paper, the current material for the pin used is 8620 steel and the current sleeve material used is 4140 steel. 8620 steel has a core Rockwell C hardness of 30-34 and the exterior surface Rockwell C hardness is 50-54. For the sleeve material, the current material used is 4140 steel with Rockwell C hardness of 38-40 and surface microhardness of 600-650 HV which converts to about 54-56 HRC. The current hardness measurements show that the pin material is harder than the sleeve while the surface hardnesses are about the same. As the pins move up and down and there is some lateral movement of the pins, this leads to pins rubbing against the sleeves and the sleeves wearing out due to friction. As the pins collide with the sleeve material and since the material is softer or about the same hardness, the sleeves wear out before the pins as the harder material of the pins slide against the sleeve material. This is resulting in the sleeves wearing out before the pins. In order to prevent the sleeves from wearing out, the material for the pins needs to be softer than that of the sleeves.

Since the idea was to make the sleeve material harder than the pin material, various materials were researched including tool steel. D2 tool steel was considered for the sleeve material initially. This was however deemed not feasible as it would increase the cost of machining the sleeves out whenever they need to be replaced. Therefore, design changes to the sleeves were made and a collar was added at the top of the sleeve which would be press fit.

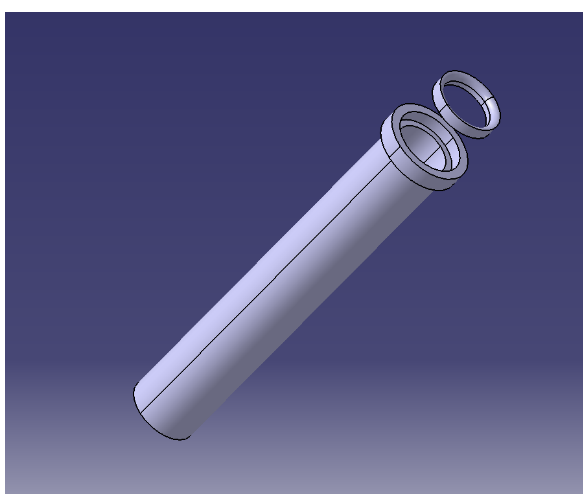

Figure 2: Sleeve design with insert collar

Figure 2 above shows the sleeve design with the insert ring at the top that would be press fit in the sleeve. The sleeve material was changed to 8630 steel, a grade higher than the pin material which is 8620 steel, in order to increase hardness of the sleeve. For the insert ring, since this is the high area of wear as the pins hit this area as they come down each stroke, tool steel was deemed a better option. Therefore, the material for the insert collar was chosen to be an A8 tool steel in order to further increase the hardness of the sleeve so that the sleeves are harder than the pin. Since tool steel is more wear resistant, it will increase the wear resistance of the sleeves and ensure that the sleeves are safe. Finite element analysis was conducted on this new sleeve design using the newly selected materials and the results are shown in the figure below.

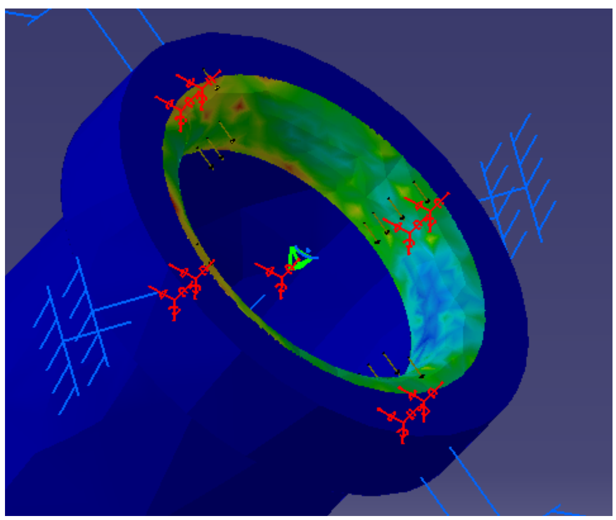

Figure 3: FEA of sleeve design

The FEA results of the sleeve design using 8630 steel for the sleeve and A8 tool steel for the collar show that the sleeve is able to withstand the forces placed on it. The mostly green and blue color in the image above show that the stress on the collar and the sleeve are low and more spread out, therefore they will be able to withstand the high load from the pins as they slide past the sleeves.

In terms of tool wear between the pins and the binder, the friction between the sliding surfaces needs to be reduced in order to reduce wear. A screw-on puck was added on top of the pin so that the top portion can be a low friction material in order to reduce friction between the pins and the binder. Figure 4 below shows the design changes that were made to the pins for a better pin operation.

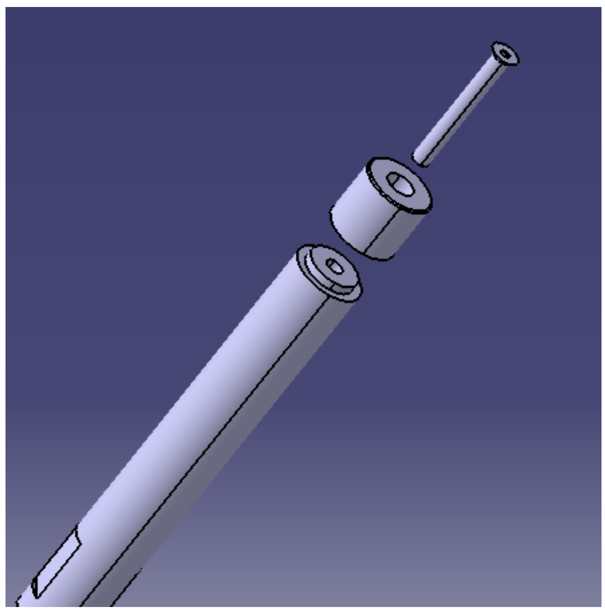

Figure 4: Final pin design with screw-on puck using allen bolt

Since the puck was designed to reduce friction between the pins and the binder, the material for the puck needed to be a low friction material. Various low friction materials were researched for the puck. FEA analysis was carried out on the materials including nylon, teflon, and wear resistant bronze. All of these materials failed during FEA due to high displacement as they were unable to withstand the high load of 2500 N placed on the pins. Therefore, alternate solutions were researched instead for the puck material. In the end, the puck material was kept the same as the pin which is 8620 steel, a more durable material, and research was conducted on low friction coatings instead for the top of the puck.

After investigating through research, tungsten disulfide coating was decided for the top of the pin puck. Tungsten disulfide is a soft coating that functions much like graphite. One of the studies investigating friction of tungsten based coating under sliding contact for steel on steel concluded that tungsten disulfide coating is a very thin layer of material and very low in friction. For metal on metal contact, the shear stress will be higher regardless of a small real contact area due to surface roughness, therefore the friction will be high. The opposite of this can happen with a hard object and a soft object; the shear stress is reduced but the true contact area is much higher, and therefore there is a large friction force. By applying a thin film of a soft material, the hard material underneath prevents significant deflection, and thus, decreasing the true contact area, all the while the soft film has a low shear stress from sliding contact with a hard metal substance. This low true contact area and low shear stress result in a low friction force and reduced coefficient of friction. Furthermore, tungsten disulfide acts as a dry lubricant which eliminates the need to add further lubrication to the pins. This coating can also withstand up to 100,000 psi of load which means that it will be able to withstand the high load placed on the pins. In terms of wear, the results of the same study concluded that the coating was still intact after repeated cycles of loading under sliding conditions which means that the coating will not wear off quickly [12]. Considering the results of the research, tungsten disulfide coating was chosen for the top of the puck in order to reduce friction between the pins and the binder interface.

In order to validate that the selected materials do indeed increase wear resistance, wear analysis was carried out using two different methods. The first method used Archard's wear model to compare the wear improvement between the old and the new pin and sleeve materials. The Archard's wear equation that was used can be seen in Equation (1) below. The wear is calculated by multiplying the wear coefficient by the load and distance slid, then dividing that value by three times the hardness of the material.

$$W = \frac{K'Ld}{3H} \tag{1}$$

Since the side load from the press on the pins was unknown, the wear on the pins and sleeves was calculated at different loads. These loads were estimated using the force exerted on each pin and broken down into component forces at a given angle between 1-5 degrees. This is because the moment generated by the press makes the bolster come down at a slight tilt. The distance slid was estimated using the stroke of the press multiplied by two, as the pins go up and down, and the approximate number of cycles the press runs in a day. The coefficient of wear can be found and calculated through a pin-on-disk test. By rearranging Equation (1) and using values from the pin-on-disk test, the following equation is used to determine the wear coefficient:

$$K' = \frac{3WH}{Ld} \tag{2}$$

This value can also be commonly found in tables resulting from the pin-on-disk test. The wear coefficient is not a material property, instead, it is the relationship between two materials.

Since the pin-on-disk test was not performed in this study, handbook values were used for the wear coefficient. For the old pin and old sleeve material, which were both low-carbon steel, the wear coefficient is 0.007. The wear coefficient of the new pin is 0.00017 (low-carbon steel on tool steel), and the wear coefficient of the new sleeve used is 0.00013 (tool steel on low-carbon steel).

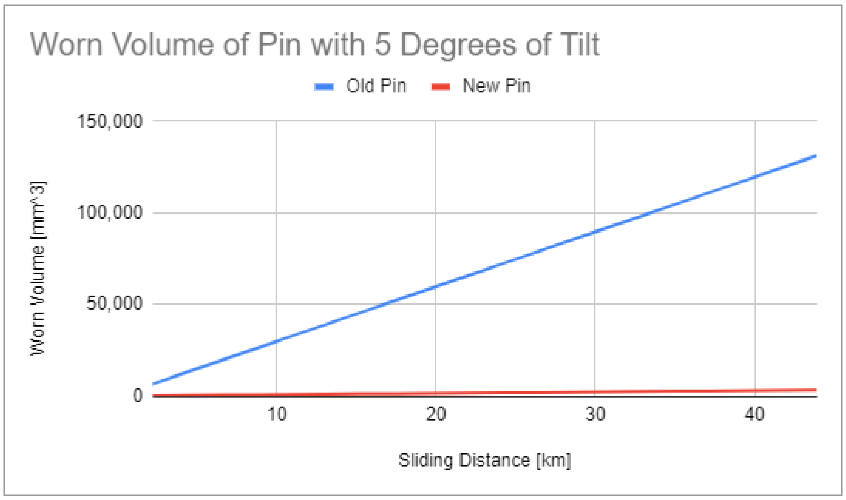

Figure 5: Worn pin volume with 5 degree tilt

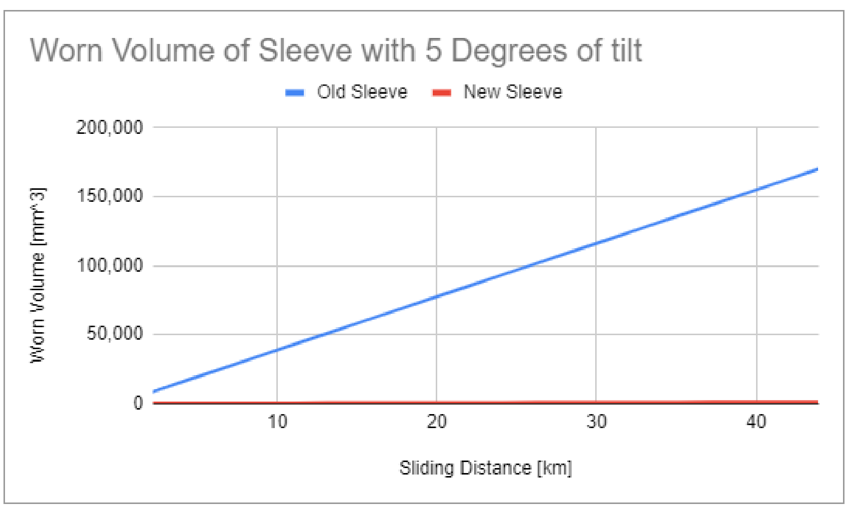

Figure 6: Worn sleeve volume with 5 degree tilt

Figures 5 and 6 above compares worn volume of old and new pin and sleeve materials, assuming the worst case scenario with a 5 degrees of tilt. The calculations assumed that the press ran 600 cycles per minute for 12 hours a day over a period of 20 days. As can be seen from the figures above, significant improvement in the amount of wear is visible when comparing the old and the new pin/sleeve designs, proving that the newly selected materials are better and more wear resistant. Overall, it was found that the wear of the sleeve was reduced by a factor of 162.6 and the wear of the pin was reduced by a factor of 41.2. In order to further confirm these findings, Ansys simulations were performed to compare the results of the Archard's wear model with. The pin and sleeve were modeled inside of Ansys to determine the frictional stress between the two components. This value was used to determine the wear volume utilizing the following equation.

$$W = K * F * V * T \quad (3)$$

In this equation, K is the wear coefficient, F is the frictional stress, V is the velocity and T is the time. Handbook values were again used for the wear coefficient of each material.

Table 1. Material Properties

	4140 Steel	8620 Steel	A8 Tool Steel
Density (g cm^-3)	7.85	7.8611	7.87
Young's Modulus (Pa)	2.016E+11	2.068E+11	2E+11
Poisson's Ratio	0.26	0.29	0.28
Bulk Modulus (GPa)	140	164.16	151.52
Shear Modulus (GPa)	80	801.72	78.125

Table 1 above displays the material properties that were utilized for the Ansys simulation. The original materials were tested against the newly found materials. The Ansys simulation was created based on a simplified geometry of each part. The results of the simulation came very close to the results obtained from the calculations done using Archard's wear model.

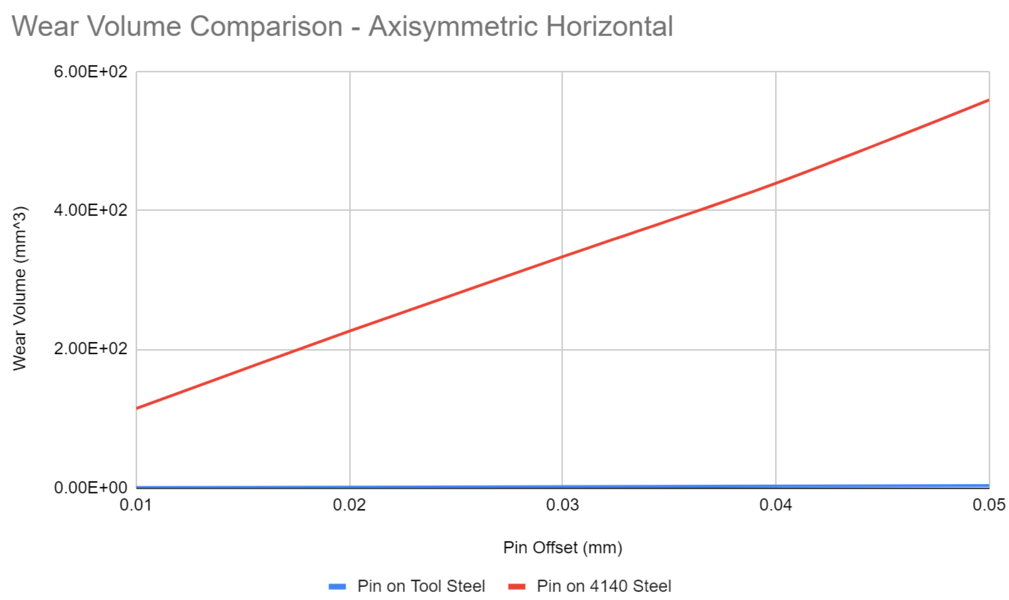

Figure 7: Wear volume of pin/sleeves using Ansys simulation

Figure 7 above shows the simulation results. The pin offset refers to the amount of interference between the pin and sleeve. The interference is added to create a level of stress that is easily adjusted utilizing parameters within the software. As can be seen from the figure, very much like the Archard's wear model, the results show a great improvement in wear with the new materials for the pin/sleeve. The wear volume of the original materials is much greater than that of the pin against the tool steel, the new material. With the Ansys simulation, an improvement in wear with the new materials was found to be by a factor of 159. The results of both models thus suggest that the new pin/sleeve designs are better in terms of reducing wear on the pins and sleeves. Therefore, it can be concluded that using a harder material increases wear resistance of the tool and adding a surface coating reduces friction between the tool interface and hence, further decreasing wear.

Future Testing

Since this paper does not conduct any experimental studies to confirm that the selected materials and design changes does in fact reduce wear on the cushion pins and sleeves, an experimental procedure is suggested for future studies. It is suggested that a pin-on-disk wear test be conducted to calculate the wear coefficients of the materials directly instead of using handbook values for more realistic results. A pin-on-disk test is a sliding wear test commonly used as a tribological characterization technique to estimate the coefficient of friction and wear mechanism of studied samples [13]. It is recommended that this test is conducted on the proposed materials and the values gathered from the experiment are used to calculate wear volume in order to get a more realistic depiction of how the wear is reduced with selecting harder materials for the die tools.

Conclusion

The sliding wear mechanism and its effect on tool wear was analyzed in order to reduce wear between cushion pins and sleeves. Current pin and sleeve material was replaced in order to reduce wear between the pins and the sleeves. The current material for the pin used is 8620 steel, which is harder than the sleeve material that is 4140 steel. The sleeve material was changed to 8630 steel with an A8 tool steel insert ring at the top in order to increase the hardness of the sleeve so that the sleeves are harder than the pin. This was done to increase wear resistance of the sleeves and ensure that the sleeves are safe. Numerical wear analysis was conducted using Archard's wear model and Ansys simulation and the results concluded that the wear on the sleeves is reduced by a factor of 162.6 and 159 respectively.

In terms of tool wear between the pins and the binder, the friction between the sliding surfaces needs to be reduced in order to reduce wear. A screw-on puck was added on top of the pin which will be 8620 steel, the same material as the pin. Low friction tungsten disulfide surface coating was added to the puck in order to reduce friction between the pins and the binder. Tungsten disulfide acts as a dry lubricant which also eliminates the need to add further lubrication to the pins. Using a harder material increases wear resistance of the tool and adding surface coating further reduces wear between tools which will decrease wear. In order to test for wear behavior, a pin on disk test as an experimental procedure was recommended to run wear analysis on the selected materials for the cushion pins and sleeves. Reducing sliding wear on the sleeves and between the pins and the binder can ensure longevity of the die tools and also lead to better quality of the produced parts.

Bibliography

[1]. Bang, Park, N., Song, J., Kim, H.-G., Bae, G., and Lee, M.-G. "Tool Wear Prediction in the Forming of Automotive DP980 Steel Sheet Using Statistical Sensitivity Analysis and Accelerated U-Bending Based Wear Test," *Metals (Basel)*, 11(2), 306–, 2021.

[2]. Y. Zhou, and W. Jiang, "Effect of sliding speed on elevated-temperature wear behavior of AISI H13 steel," *Journal of Iron and Steel Research International*, 28, 1180–1189, 2021.

[3]. N. Broqvist, S. Hogmark, A. Medvedeva, and S. Gunnarsson, "On wear resistance of tool steel," *Journal of Manufacturing Processes*, 14(3), 195–198, 2012.

[4]. G. Y. Baek, G. Y. Shin, K. Y. Lee, and D. S. Shim, "Mechanical Properties of Tool Steels with High Wear Resistance via Directed Energy Deposition," *Metals (Basel)*, 9(3), 282–, 2019.

[5]. N. Wulbieter, P. Fabian, and W. Theisen, "Influence of Hot Hardness and Microstructure of High‐Alloyed Powder Metallurgical Tool Steels on Abrasive Wear Behavior at Elevated Temperatures," *Steel Research International*, 91(5), 1900461–n/a, 2020.

[6]. Salunkhe. Sachin, Chandankar. Pavan, M.Chandankar. Vinod and Davim. J, "Wear Resistance Performance of Die Casting Materials: A Review," *Journal of Manufacturing Technology Research*, 12, 2021.

[7]. J. Mucha, and J. Tutak, "Analysis of the Influence of Blanking Clearance on the Wear of the Punch, the Change of the Burr Size and the Geometry of the Hook Blanked in the Hardened Steel Sheet," *Materials (Basel)*, 12(8), 1261–, 2019.

[8]. A. K. Jain, M. Kumar, and G. D. Thakre, "Effect of the Material Hardness and Operating Conditions on the Friction and Wear During Lubricated Sliding," *Advances in Engineering Design,* 115-126, Springer Singapore, 2021.

[9]. O.A. Zambrano, J.A. Gómez, J.J. Coronado, S.A. Rodríguez, “The sliding wear behaviour of steels with the same hardness,” *Wear*, 418–419, 201-207, 0043-1648, 2018.

[10]. Qiao, X., Cheng, A., Nie, X. et al. “A study on die wear prediction for automobile panels stamping based on dynamic model,” *Int J Adv Manuf Technol* 97, 1823–1833, 2018.

[11]. T. Hillskog, “Choosing the proper steel to minimize abrasive adhesive tool wear,” *Stamping Journal*, The Fabricator, 2003.

[12]. Marko, M.D. “Friction of Tungsten-Based Coatings of Steel under Sliding Contact,” *Lubricants*, 7, 14 2019.

[13]. Federici, M., Straffelini, G. and Gialanella, S. “Pin-on-Disc Testing of Low-Metallic Friction Material Sliding Against HVOF Coated Cast Iron: Modelling of the Contact Temperature Evolution,” *Tribol Lett* 65, 121, 2017.