Effects of Temperature in Relation to Sheet Metal Stamping

PAUL C OKONKWO[1)], MICHAEL P PEREIRA[1)], GEORGINA KELLY[1)], BERNARD F ROLFE[2)]
[1)] Centre for Material and Fibre Innovation [2)] School of Engineering
Deakin University
Geelong Waurn Ponds Campus
AUSTRALIA
pcok@deakin.edu.au

Abstract: - The demand to reduce the use of lubricants and increase tool life in sheet metal stamping has resulted in increased research on the sliding contact between the tool and the sheet materials. Unlubricated sliding wear tests for soft carbon steel sliding on D2 tool steel were performed using a pin-on-disk tribometer. The results revealed that temperature has an influencing role in the wear of tool steel and that material transfer between tool and sheet can be minimized at a certain temperature range in sheet metal stamping.

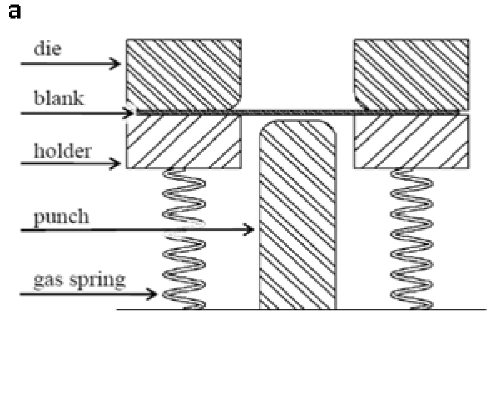
Keywords: - Tool wear, Frictional heat, D2 tool steel, sheet- metal stamping, pin-on-disc wear test.

1 Introduction

In sheet metal forming, the wear of tool steel continues to be a great concern to the automotive industry as a result of increasing die maintenance cost and scrap rate [1-3]. D2 tool steels are used as the stamping die material in many cold forming industries due to its properties to withstand higher forming forces and wear [4, 5]. However wear of these tool steels is a common problem in the automotive industry [3, 6]. It is believed that contact pressure and temperature are fundamental factors in many tool wear processes [7, 8]. Dry sliding contact between metallic surfaces is often associated with high surface temperatures due to frictional heating and results in high friction and severe surface damage [8]. Recent studies by the authors have shown that temperatures of over 130°C may occur at the surface of stamping dies due to the increased frictional heating associated with 'cold' forming of advanced high strength steels [9]. These effects are likely to influence the wear behaviour experienced in cold forming operations but are currently unknown and will be investigated in the study.

2 Numerical Temperature Prediction in Channel forming process

diagram schematic of the channel forming process, which is typical of sheet metal forming, is shown in Fig.1. A typical stamping tool set consists of a punch, die and blank holder, as shown. The die, which is often made of hardened D2 tool steel is often found liable to wear and galling, resulting in intolerable change in the dimension of the formed auto-body part and the die surface [4]. Forming of these auto-body parts have shown to result in high temperature rise of up to 130°C at the die surface, as was recently predicted by the authors using finite element analysis [9]. Deformation heat was found to be transferred to the die surface when there was contact between the blank and the die surface, revealing the importance of contact condition in the evolution of temperature at the die surface throughout the channel forming process. This high temperature on the blank which is in contact with the die during the forming process may be an influencing factor that affects the wear of the D2 tool steel die material during the cold forming operation. Laboratory and experimental investigation of the predicted temperature range on the wear of D2 tool steel material becomes necessary.



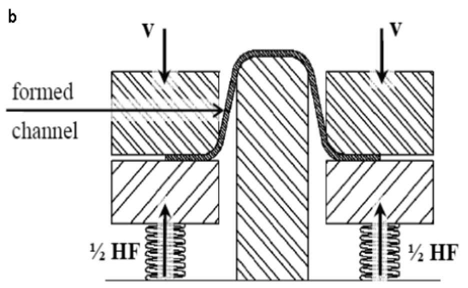


Fig.1 Schematic diagram of channel forming operation (a) before and (b) after forming operation

3 Experimental set-up

In order to simulate the contact and temperature conditions during the channel forming process, unlubricated sliding wear tests were performed using a pin-on-disc tribometer as shown in Fig. 2. The tests were performed at two different temperatures of ambient and 150°C. The slowest possible speed of 10mm/s was chosen for the test to minimise the effect of frictional heat and a constant 5N load was applied while the sliding distance and temperature were varied for the different tests. The hardness of the ball and the disc materials were measured to 26± 0.5 and 60± 0.5HRC, using 98.07N load on the digital Vickers hardness tester. The roughness of the ball and the disc were measured to be 0.008±0.003 and 0.04± 0.001µm respectively, using a Taylor Hobson Talysurf profilometer. The important parameters used in the pin-on-disc tests are summarised in Tables 1 and 2. The wear tracks on the disc were characterised using optical profilometry and scanning electron microscope (SEM).

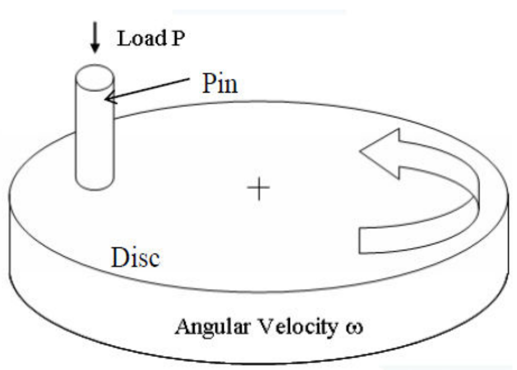


Fig.2 Pin-on-disc tribometer specimen configuration

Table 1: Summary of pin-on-disc test parameters

Parameter	Unit	Value(s)
Ball diameter	mm	6.35
Load	N	5
Sliding speed	mm/s	10
Number of revolutions	-	200
Wear track diameters	mm	9, 13,17 ,21± 0.1
Testing temperature	°C	25 ±2, 50 ±0.5, 100 ±0.6, 150 ± 0.6

Table 2: Summary of materials tested

Material	Specimen	Chemical composition [%wt]
AISI D2	Disc	Fe C Cr Mo V Bal.1.55. 12.28 .81 .74
AISI 1018	Ball	Fe C Mn Si S Bal. .13 .30 .01 .02.

4 Results and Discussion

The results reveal a transition in the dominant wear mechanism of D2 tool steel within a cold forming process temperature range condition.

4.1 Profilometry Examination:

Material loss from the D2 disk and wear volume of the balls were determined from the cross sections and contact profilometry as shown in Fig. 3.

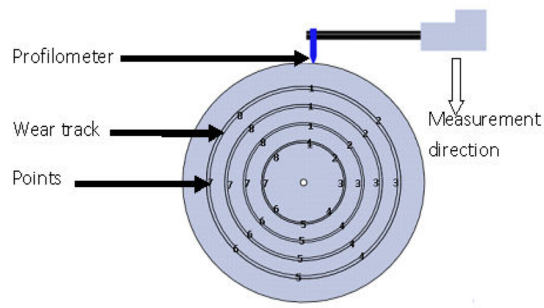
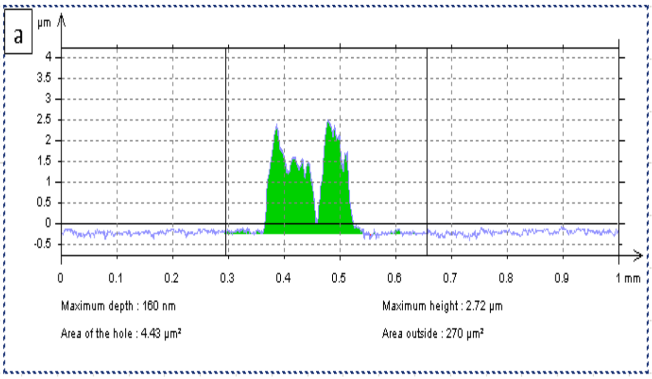


Fig.3 Profilometry measurement of disc

The surface profiles of the tool steel disc surface were determined using a Taylor Hobson Stylus profilometer. The profilometer stylus was moved across the wear track sliding direction with a test speed of 20mm/min as shown in Fig.3. To calculate the average wear volume of tool steel at each temperature, the profile results from profilometry measurements of each of the eight equally spaced points on each of the wear track were further analysed using Talysurf software. The Talysurf profile displayed the depth, heights and areas of the materials above and below the worn surface (Fig.4 (a-b)). Each column shown in Fig 5 was calculated based on the average wear volumes measured at each of the 8 profile measurements for each of the 4 wear track diameters. The error was based on the average of the wear volume of the eight points on each of the wear diameters. The Talysurf profile results of the ambient and 150°C tests of the D2 tool steel specimen were analyzed to calculate the wear volume and possible wear transition in wear mechanism throughout the entire temperature test range as shown in Fig. 5.



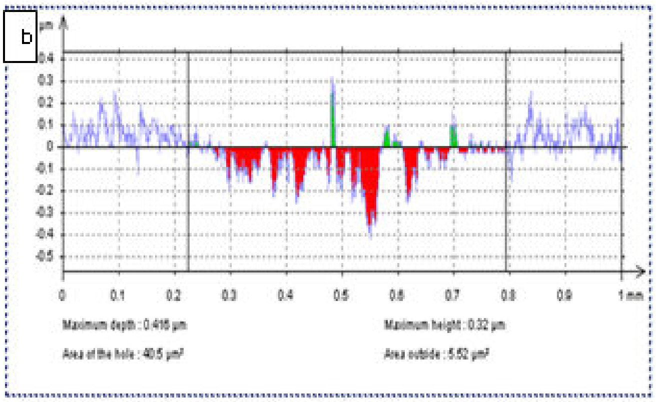


Fig.4.Profilometry measurements across the wear track for a) Ambient, and b) 150°C, The region between the vertical bars indicates the width of the wear track.

By examining the entire plot of Fig.5, a decrease in the material deposited on the D2 tool steel surface was found as temperature was increased from the ambient to 150 degree. However, material removal was gradually increasing from the ambient to the high temperature test conditions. Material removal at the ambient test condition was insignificant compared to the amount of material deposited. However, material removal was a dominant phenomenon at 150°C test conditions compared to material deposition experienced at lower temperature. Generally, the overall change in wear volume with respect to temperature change could be clearly seen in Fig. 5. Interestingly, the two phenomena of material deposit and removal are likely to be almost in equilibrium between 50°C and 100 °C, which could be a region of interest to the auto-motive industry where material removal from the tool steel and transfer between the tool and sheet material can be minimized.

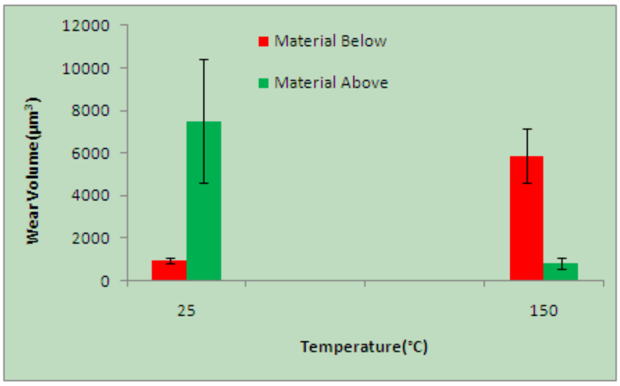


Fig.5.Wear Volume with respect to Temperature

4.2 Scanning Electron Microscope (SEM) Examination: The general wear behavior for each of the different test temperature conditions was examined using the SEM technique as shown in Fig.6. It was evident that the ball material deposit on the tool steel surface was the dominant feature observed at ambient temperature with material removal being insignificant. Conversely, at 150°C, material removal from the tool steel surface due to spalling and ploughing of the tool steel surface was found to be the dominating wear mechanism.

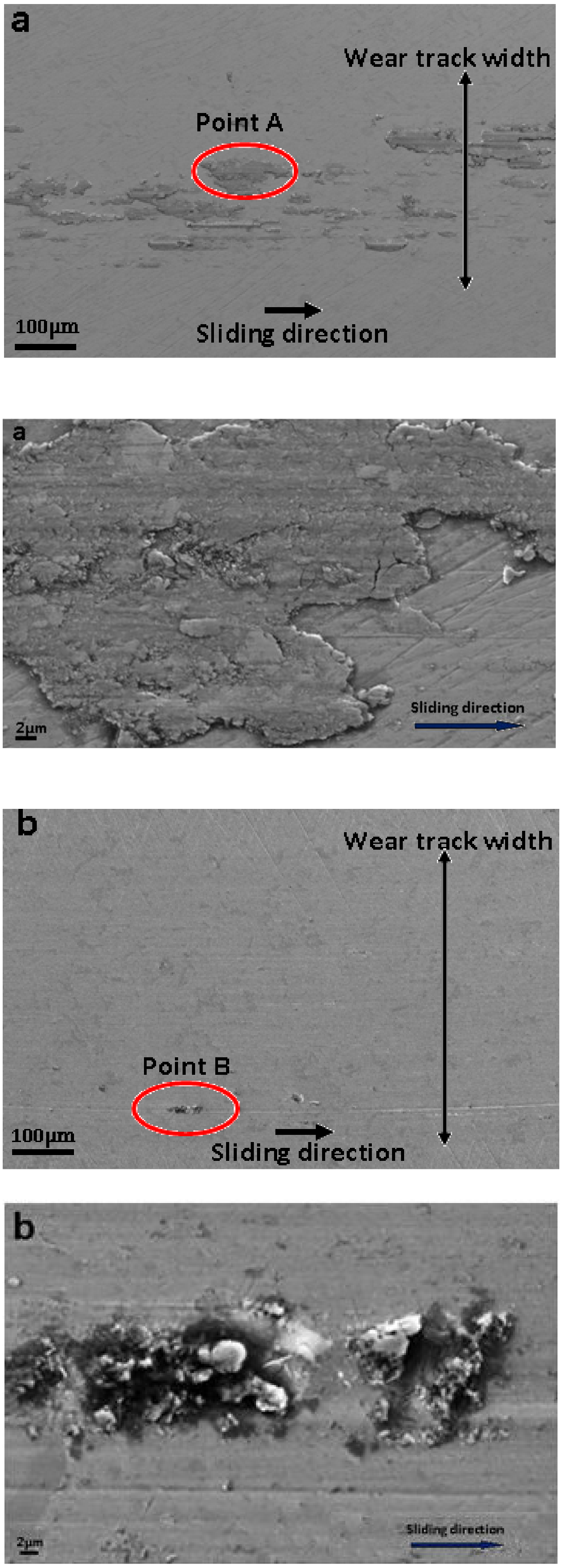


Fig.6 SEM micrographs of a)ambient test temperature showing Point A at higher magnification and b) 150°C test temperature showing Point B at higher magnification

The micrographs shown in Fig. 6, qualitatively correlate well with the wear volume measurements shown in Figure 5. This result demonstrates that there is a significant change in wear mechanisms between the ambient and 150°C tests.

The results of these tests show a transition from galling at ambient temperature, to abrasion at 150°C. Previous results in the literature have shown that galling is typically accelerated as temperature is increased during both lubricated and unlubricated conditions [10, 11]. However, it is evident that this increased tendency towards galling at increased temperature was not observed in this investigation. The authors speculate that the increased temperature may result in increased oxidation at the ball and disc surfaces, thus decreasing the tendency for adhesive wear mechanisms. However, this reason will need to be investigated further.

4.3 Correlation of predicted temperature with experimental result:

High temperature has been predicted at the die surface of channel forming process and this may be critical to the overall wear mechanisms being experienced in the forming process. The pin-on-disc test carried out on D2 tool steel within the temperature range predicted by the above forming process has the potential to give insight into the industrial wear phenomena using a laboratory test. Classification of these wear mechanisms on the die surface in cold forming process using a laboratory technique is useful to understand the fundamental wear mechanisms prevailing and find possible ways of controlling the tool wear.

Furthermore, repeated stamping operations could cause an increase in temperature resulting in the transition from low to high temperature wear mechanisms observed in this study. This transition in wear mechanism, according to Bohr et al. [12] occurs on the die surface with increasing repeated number of cycle. This was also evident in SEM of worn surface of D2 tool steel of Fig.6, where adhesion of the ball material on the tool steel surface at lower temperature and spalling and ploughing of the tool steel surface at a higher temperature were observed.

ISBN: 978-1-61804-031-2

Fig. 5 shows the transition in wear volume as the temperature was increased indicating a change in dominant wear mechanism which was confirmed by SEM images of Fig.6. It therefore becomes clear that an increase in temperature as a result of repeated stamping could have a significant effect on the overall wear mechanism of the tool. Therefore, identifying process conditions that reproduce the temperature range where both mechanisms are minimized may be a way of reducing the tool wear problem in sheet metal stamping.

5 Conclusion

The effect of temperature on the wear of D2 tool steel was examined using pin-on-disc laboratory test. It was found that there was a transition in dominant wear mechanisms from adhesion of ball material to the tool surface at lower temperature to ploughing and spalling of the tool surface at the higher temperature. Such observation has not been reported in literature. It was concluded that such wear mechanisms and transition as a result of increased temperature due to repeated stamping operation could be critical to the overall wear behaviour being experienced in cold sheet metal stamping.

References:

[1] M.P.Pereira, W.Yan., B. F. Rolfe, Contact pressure evolution at the die radius in sheet metal stamping. *Journal of materials processing Technology*, 2008.

[2] H.Kim, J.S., F.E.Goodwin,A. Taylan , Investigation of galling in forming galvanized advanced high strength steels (AHSSs) using the twist compression test (TCT) J*ournal of material processing Technology,* 2007. **205**(2 0 5 (2 0 0 8) 459-468): p. 459-468.

3. M.P.Pereira, W.Yan., B. F. Rolfe, Contact Pressure evolution and its relation to wear in sheet metal forming. *Wear*, 2008. **265**: p. 1687-1699.

4. Ö.N.Cora,. and M. Koç, Experimental investigations on wear resistance characteristics of alternative die materials for stamping of advanced high-strength steels (AHSS). I*nternational Journal of Machine Tools and Manufacture*, 2009. **49**(12-13): p. 897-905.

5. M.P.Pereira,W. Yan, and B.F. Rolfe, Contact pressure evolution and its relation to wear in sheet metal forming. *Wear*, 2008. **265**(11-12): p. 1687-1699.

6. T.Skare, F.Krantz., Wear and frictional behaviour of high strenght steel in stamping monitored by acoustic emission technique. *Wear,* 2003. **255**: p. 1471-1479.

7. W.Yan, E.P. Busso, and N.P. O'Dowd, A Micromechanics Investigation of Sliding Wear in Coated Components. *Proceedings: Mathematical, Physical and Engineering Sciences*, 2000. **456**(2002): p. 2387-2407.

8. T.Herai,M.Ejima,K.Yoshida,K.Miyauchi. H.Ike, Frictional surface damage and its mechanism in metal sheets. *Scientific Papers of the Institute of Physical and Chemical Research*(Japan), 1978. **72**: p. 1-13.

9. M. P.Pereira, P.C.Okonkwo, W. Yan,B. F. Rolfe. Deformation and frictional heating in relation to wear in sheet metal stamping. *13th International Conference of Metal Forming*. 2010. Toyohashi,Japan.

10. E.van der Heide, D.J.Schipper, Galling Initiation due to frictional heating. *Wear*, 2003. **254**: p. 1127-1133.

11. A.Gåård, N.H., P.Krakhmalev,J.Bergström., Temperature effects on adhesive wear in dry sliding contacts. *Wear*. **268**(7-8): p. 968-975.

12. C.Boher,D.Attaf,L.Penazzi, C.Levaillant , Wear bahaviour on the radius portion of a die in deep-drawing:Identification,Localisation and evolution of the surface damage. *Wear*, 2005. **259**: p. 1097-1108.