

# Study of wear performance of deep drawing tooling

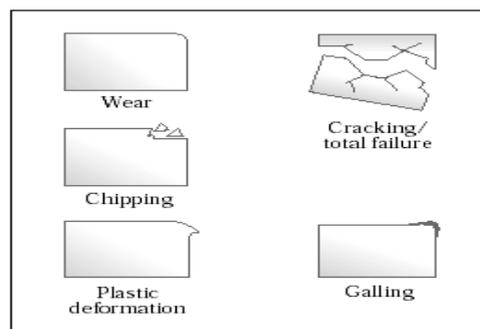
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**Abstract.** One of the most common challenges for many of the mechanical engineers and also in the field of materials science is the issue of occurrences of wear of the material parts. In this paper, wear behaviour of particular grade High Carbon High Chromium Steel and many most famously D2, H13, O1 known as the Viking steel has been studied, evaluated and analyzed on pin-on-disc machine. The specimens have been subjected under different processing parameters such as speed, load, track diameter and time under dry sliding conditions at normal room temperature to replicate the deep drawing process. The present research work will help to investigate the wear behaviour of the deep drawing die tool to characterize the mechanical & tribological properties of die steel and developed a statistical model to predict wear under dry conditions for deep drawing process.

## 1. Introduction

Deep drawing is one of the typical sheet metal forming process used to produce axisymmetric and irregular hollow shaped parts through combined action of tensile and compressive deformation of sheet metal blank. It is popular because of its rapid press cycle to produce complex axisymmetric geometries [1]. The life of deep drawing die components is generally governed by many factors such as design of die components, selection of materials, heat treatment, techniques of manufacturing of die components, work material, production conditions and the maintenance of press tool components. Failure investigations on numerous worn-out dies from many different applications specify that five main failure mechanisms are encountered of deep drawing tooling. These are wear, chipping, plastic deformation, cracking/total failure, and galling. Figure 1 shows various failure mechanisms in sheet metal tooling.



**Figure 1.** Most Frequent Failure Mechanisms in Sheet Metal Tooling [2]

The wear observed in deep drawing tooling has been classified as abrasive wear, adhesive wear, mixed wear. Abrasive wear dominates when the sheet material is hard and/or contains hard particles such as oxides or carbides. Microscopic examination shows that the tool steel properties that are important for good resistance to abrasive wear are high hardness, high volume of carbides, high hardness of the carbides and large carbide size. Adhesive wear occurs with soft and adhesive sheet materials such as aluminium, copper, stainless steel and low carbon steels. The mechanical properties of die components

that are critical for good resistance to adhesive wear are high hardness, low coefficient of friction between the tool and work material, and high ductility. It should be noted that not all sheet materials causes purely abrasive or purely adhesive wear. Some cause partly adhesive and partly abrasive wear. This type of wear is designated as mixed wear. The present research work is planned to investigate the wear behaviour of the deep drawing die tool to characterize the mechanical & tribological properties of die steel and to develop statistical model to predict wear under dry conditions. In this research punch and die work material consider is high carbon, high chromium Viking steel. It offers very high toughness and wear resistance used for manufacturing of punches and dies of deep drawing tooling.

## 2. Literature review

In this literature review, the various issues pertaining to wear behaviour of tool steels and various testing methods are discussed. Cockeram et al. [3] developed a four promising coating approaches using scratch adhesion and indentation testing for cobalt based alloys. Bahrami et al.[4] investigated the effects of conventional heat treatment on wear resistance of AISI H13 tool steel and effects of in situ surface tempering on AISI H13 tool steel. Lima et al. [5] have made an analysis of AISI D2 tool steel of cold work and AISI 4340 low alloy steel of high strength both of them under hard turning process. Bourithisn et. al [6] have made an investigation using the same hardness (60HRC) of the AISI O1 and AISI D2 tool steels and compared wear properties between them. Rendón and Olsson [7] performed investigation on some commercial abrasion resistant steels to find abrasion wear resistance. Kim et al.[8] established guidelines to select the optimum combination of die materials, coatings and lubricants in stamping galvanized AHSS (DP600, TRIP780 and DP980) for automotive structural parts.

Cora et al.[9] investigated the wear performance of different coatings (two different PVD, CVD and TD coating) applied onto variety of substrate materials (DC 53, SKD 11, DRM 3, DRM 51) against AHSS sheet blanks. A non-reciprocating, CNC-based, slider type of tester was employed in wear tests. Further, Cora et al.[10] developed a new slider type of test system replicate the actual stamping conditions including the contact pressure state, sliding velocity level and continuous and fresh contact pairs (blank-die surfaces). Vilaseca et al.[11] analysed tribological behaviour of two sets of industrial hot stamping tools, one tool made of uncoated hot work tool steel and another PVD coated hot work tool steel set, by means of a surface replication technique. Witulski et al.[12] developed a methodology for the rapid production of drawing tools with high wear resistance to form free-form shaped sheet metal parts. Shih[13] developed a rephosphated steels applying the phosphate coating on zinc coated sheet steels to increase the lubricity in the automotive stamping process and adding extra corrosion protection. He investigated the tribological performance and die wear behaviour of pre-phosphate AHSS in the die tryout and production conditions.

From the reviewed literature it is found that various researches has been done for the wear testing of high carbon high chromium material especially using the AISI D2 grades and experimentation with various coatings. Also these grades of tool steels are not only being performed a comparison wear behavior test amongst each other but also amongst other grades of higher and rougher applications especially used for hot work, plastic moulding and power metallurgy types of applications. The issue still stands since there are extremely less research happening when it comes to high carbon high chromium steels of these grades such as Assab88( Sleipner), Caldie and Viking. Further it is found that most of researchers performed the experimental investigation to determine the wear behaviour of AISI D2 grade steel and proposed few mathematical models based on statistical regression techniques. But research for viking grade material is rarely been done for wear testing purposes. Hence there is a need to study the wear behavior of Viking grade steel. Hence in present study an experimental investigation has been carried out under dry sliding condition to determine wear behaviour of Viking grade steel under different process parameters. The main aim was to study the influences of various process parameters such as applied load, sliding distance, sliding speed under dry sliding wear of the Viking grade steel with the help of factorial experimental design under various testing conditions. Furthermore, the analysis of variance (ANOVA) is employed to examine to test various characteristics of Viking grades steel.

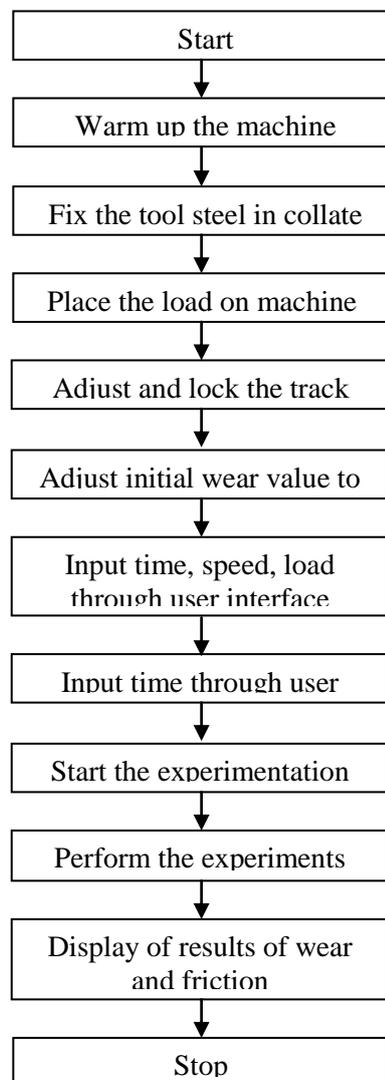
### 3. Experimental details

The experimentation has been carried out on *Viking grade HCHC tool steel*, it is also known as high carbon high chromium steel. This steel offers very high toughness and wears resistance and used for manufacturing of punches for sheet in copper, stainless steel, zinc, brass, hard abrasive. Further, it also used for other applications such as deep drawing dies, cold extrusion dies, trimmer dies, cupping dies, plug gauges, blanking special taps, broaches etc. The specimen preparation and experimentation were carried out according to ASTM standards. The mechanical properties of Viking grade stainless steel material has a hardness of 58 HRC, yield strength of 1960 N/mm<sup>2</sup>, density of 7.75 k/m<sup>3</sup> and modulus of elasticity 190000 N/mm<sup>2</sup>. Table 1 gives the chemical composition of the materials used in the investigation.

**Table 1.** Chemical Properties of Viking grade HCHC tool steel

Components	C	Si	Mn	Cr	Mo	V
Wt%	0.5	1	0.5	8	1.5	0.5

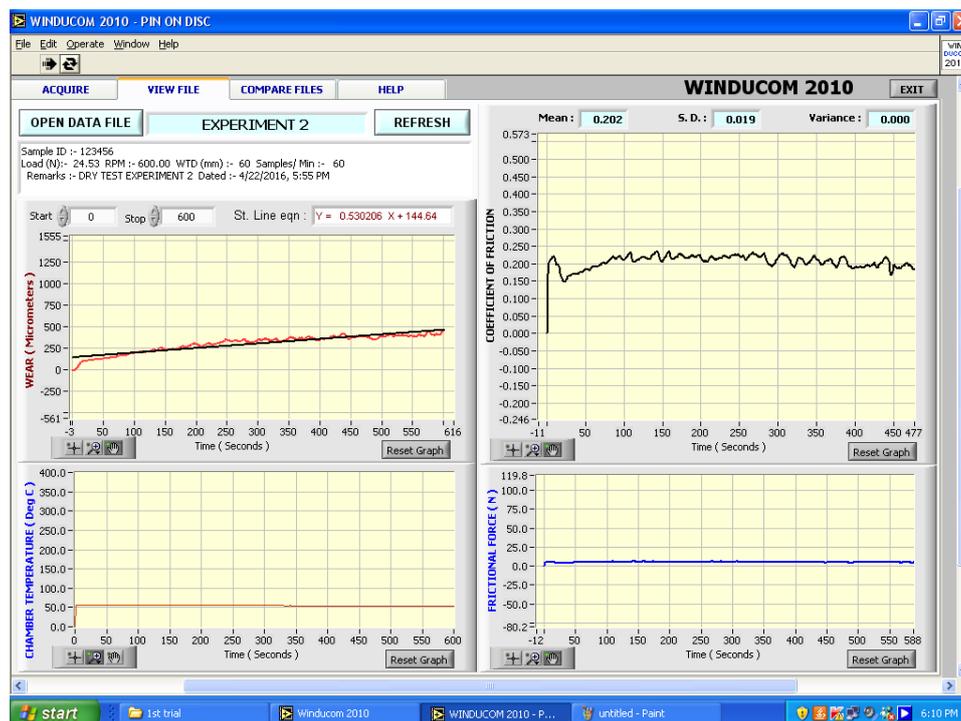
Experimental procedure followed for determination of wear is shown in Figure 2. Before start of all tests, the specimens and holders were thoroughly cleaned in petroleum spirit in an ultrasonic cleaner, thereafter rinsed with ethanol and dried in air.



**Figure 2.** Experimentation Flow Chart.

For each of the speed of the rotating disc these three loads will be experimented on the pin. The track diameter is considered to 60 mm and 75mm and duration of each of the experiment is considered to be 10 minutes. The output parameters to be obtained from the experimentation are the wear rate of the tool steel in micro-meters/meter and the coefficient of friction of the tool steel. Also the minimum wear rate of the tool steel, the maximum wear rate of the tool steel and the mean or the average wear rate of the steel is also considered. Initially the machine has to be switched on and the warming up of the rotating disc has to be performed at around 500 rpm for 1 to 2 minutes. After the automatic stopping of the warm-up rotation of the disc, the track diameter which was considered is now set up, screwed and locked.

At the end of the arm is where the pin or the tool steel is being held and it consists of collate. There are various shapes and sizes of collates depending upon the shape and size of the tool steel. A squared shaped with a dimension of 10 mm x 10 mm tool steel is being used for experimentation. The tool steel is placed in such a way that there is a sufficient hard contact between the tip of the pin and the rotating disc without any load and the pin is then fixed and screwed tightly. Lastly for desired input parameter, the desired load is then placed. Now the duration of the time is set which is 10 minutes and the initial wear value of the pin is set to a tolerance limit between +30 to -30 by fine tuning of the two sensitive lead screws. The DUCOM Micro POD pin-on-disc tribometer is interface with automatic data acquisition system. Initially, through user interface all input parameters such as speed, load, and duration and track diameter enter into system. During experimentation the system recorded wear behaviour and coefficient of friction readings of the tool steel on computer screen as shown in Figure 3.



**Figure 3.**Screen shot of acquisition of wear behaviour and coefficient of friction.

#### 4. Test equipment

For the wear testing of Viking grade using Pin-On-Disc tribometer, the DUCOM Micro POD Pin on Disc machine is being utilized is shown in Figure 4. The Ducom Micro PoD comprises of a precision controlled drive that controls disc rotation. The counter specimen, which may be a ball, pin or any other custom geometry, is held firmly in a friction/loading arm. A known load is applied upon the counter specimen to achieve the desired contact stress. The Micro PoD is a fully computer controlled

test system. The operator may choose and set the desired test parameters through the user interface provided on DucomTribo.



**Figure 4.** DUCOMMicroPOD pin-on-disc Tribometer.

## 5. Design of experiments

The most important stage in the plan of experiments is selection of factors. The input parameters that are considered for this experiment are the speed of the rotating disc and the load which will be transferred to the stationary pin that applied on the rotating disc. The levels of the input parameters for the rotating disc are considered to be 600 rpm, 900 rpm and 1200 rpm and for the load it is considered to be 1.5kg, 2.5kg and 4.0kg. For each of the speed of the rotating disc these three loads will be experimented on the pin. The track diameter is considered to be 60 mm and 75mm and the duration of each of the experiment is considered to be 10 minutes. Table 3 indicates the process parameters and their levels.

**Table 2.** Process parameters and their levels

Factors	Levels		
	I	II	III
Load (N)	1.5	2.5	4.0
Speed (rpm)	600	900	1200
Track Dia. (mm)	60	--	75

Three level factorial experiments create to investigate the effect of load, speed and track diameter on wear of Viking steel. About 27 experimental runs were conducted by including the effect of randomization and replication. The experimental results were analyzed using analysis of means and variance to study the influence of factors. The Experiments were conducted as per the standard factorial design so as to investigate which design parameter significantly affects the dry sliding wear for the selected combinations of load, sliding speed and sliding distance and material.

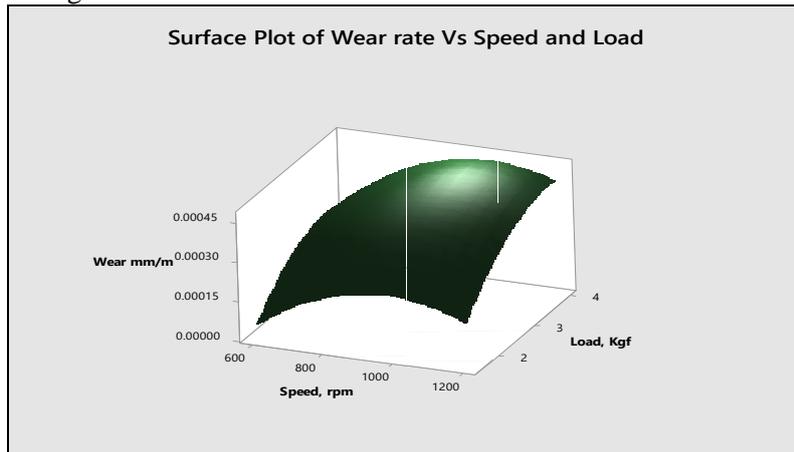
## 6. Results and discussions

In order to identify the main controlling parameter(s) which having influence on the wear behaviour of Viking grade steel during operation, an experimentation has been carried out on DUCOM Micro POD pin-on-disc Tribometer. The observations from the investigation have been summarized and discussed in following section.

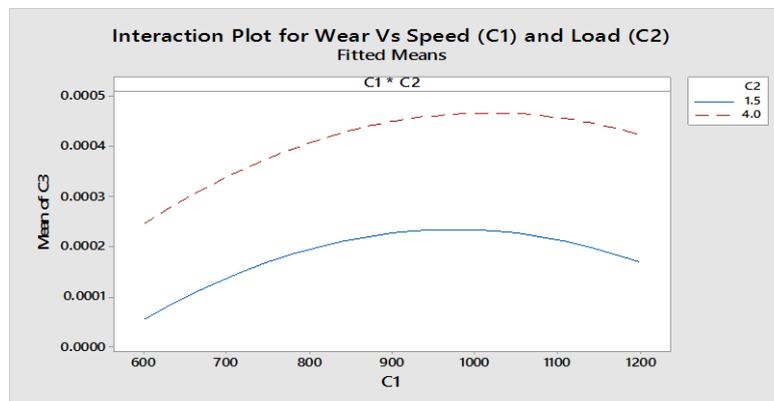
### 6.1. Influence of load and speed on the wear behavior

The load has a significant influence on the wearloss of the material. Figure 5 represents the variations of wear rate of the Viking grade steel as a function of applied load for a constant sliding distance 65mm and speed 700rpm, 900 rpm, 1200 rpm at normal room temp. It may be noted that wear rate of Viking grade steel metal increased with increasing load. The wear rate of metal is depended on the heat treated conditions of the metal and the applied load. During this process, transfer of pin material to the disc was also observed. This type of seizure has been referred to as galling seizure which leads to

further increase in wear rate. Wear rate of normal specimen increases gradually with applied load. The wear rate of the pin increases with increasing speed. As the speed increases the temperature increases which leads to plastic deformation of the material. At lower speeds the pin surface experiences severe damage resulting in a high wear rate. It can be noticed the wear rate increases with the increase in speed. If the normal specimen is considered the wear is increasing continuously upto 900 rpm beyond which it becomes stable up to 1000 rpm due to the formation of the smeared layer and wear rate start reducing continuously from 1050 rpm to 1200 rpm. Figure 5 shows the surface plot for wear rate and effect of speed and load on wear of Viking grade steel and the interaction plot between speed and load on wear is shown in Figure 6.



**Figure 5.** Surface plot for wear rate and effect of speed and load.



**Figure 6.** Interaction plot between speed and load on wear.

**7. Analysis of variance (ANOVA)**

The ANOVA is used to investigate which design parameters significantly affect the quality characteristics. It is accomplished by separating total variability of S/N ratio, which is measured by sum of square deviation from total mean S/N ratio into contributions by each of the design parameters and the errors.

**Table 3.** Regression Statistics.

<i>Regression Statistics</i>	
Multiple R	0.9175
R Square	0.9437
Adjusted R Square	0.9372
Standard Error	1.10185

The above table 3 shows that the R square value obtained is 0.9437 and adjusted R square value is 0.9372 and this enlighten us that the model account for only 94.37% of variance in the output. This is the clear indication that this model is a statistically good model.

**Table 4.** ANOVA table

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	477.197	95.4394	78.61	0.000
Load (C1)	1	31.917	31.9174	26.29	0.000
Speed (C2)	1	4.382	4.3825	3.61	0.071
C1*C1	1	90.288	90.2876	74.37	0.000
C2*C2	1	0.345	0.3452	0.28	0.599
C1*C2	1	68.101	68.1007	56.09	0.000
Error	21	25.496	1.2141		
Lack-of-Fit	3	25.496	8.4986	*	*
Pure Error	18	0.00	0.000		
Total	26	502.692			

From the above ANOVA table 4 it is inferred that the percentage of each factor contribution on the total variation and thus exhibiting the significant influence on the wear of the steel. The contribution of applied load is greater which may be due to the sufficiently induced stress at contact area within the experimental conditions. The linear regression equation for the wear loss of the Viking steel is shown in equation below:

$$\text{Wear (C4)} = 12.58 - 0.04775 C1 + 3.53 C2 + 0.000043 C1*C1 + 0.161 C2*C2 - 0.006311 C1*C2$$

The above equation gives a measure of contribution of each variable to the model. The coefficient indicates that for addition unit of C1 the wear rate is expected to increase by 0.04775 unit. Thus, load (C1) is influencing the wear rate. It indicates that load is the main factor on wear rate for Viking steel. It is followed by sliding speed while the sliding distance was less effective than the other parameters. The coefficients of applied load, sliding distance, sliding speed and material conditions are positive, which indicates that wear increases with the increase in the wear parameters. It indicates that load is the main factor on wear rate for Viking steel. It is followed by material conditions and sliding speed while the sliding distance was less effective than the other.

## 8. Conclusion

Based on experimental analysis carried out on the Viking grade tool steel and obtained results, it is concluded that the processing parameters that are considered for the wear operations are significant and also these parameters are significant amongst each other. Wear rate of Viking grade tool steel material increased with increasing load and speed. Since the analysis of this tool steel is of non-heat treated tool steel under dry test at normal temperature. Hence future scope would be analysis of wear behaviour of a heat treated material under dry run as well as under various lubricating oils at different working temperature. Further analysis of wear resistance and the wear behaviour of the coated and uncoated Viking grade under various lubricating oils are also some of the future scope to be considered.

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