EXPERIMENTAL INVESTIGATIONS OF EFFECTS OF PVD – COATED TOOLS ON QUALITATIVE AND QUANTITATIVE OUT-PUT FORCES AND PRESS WORK IN DRAWING AND REDRAWING ALUMINIUM AND LOW CARBON STEEL WORKMATERIALS INTO A CUP-LIKE SHAPES

Jaromír Audy
Edith Cowan University,
South West Campus Bunbury,
Robertson Drive 6230 Australia

Abstract

The aim of this paper was to study the effect of TiN (PVD) and TiAlN (PVD) coatings on the forces and press work when cup forming a Type 1200 aluminium and a Type 1010 steel work-materials. The forming experiments were conducted 15 times (both in drawing and redrawing tests) using the same type tools but in the uncoated and coated conditions. In total 45 drawing and 45 redrawing tests were carried out to study the benefits of coating in cup forming press operations. The results showed that patterns of forces and press work produced by the uncoated and coated tools tested showed qualitative agreement and quantitative differences at 95 and greater confidence level. There were no statistically significant differences in performance of TiN(PVD) coated tools compared to TiAlN (PVD) coated tools. The coated tools reduced drawing forces, on average, by 6% (for steel) and 9% (for aluminim), and redrawing forces by 16% (for steel) and 22% (for aluminium). The press work was also reduced, on average, by 6% and 10% in drawing and by 20% and 25% in redrawing the steel and aluminium, respectively.

1. BACKGROUND

Deep drawing and redrawing operations in sheet metal forming technology are successful production methods for manufacturing hollow cylindrical components such as cups from metal blanks [1 to 6]. It has long been recognized that the way in which blank behaves when being press formed depends on blank and shell sizes, workmaterial, tool design and lubricants [1, 3 to 6]. Consequently, all these process variables influence the forces and press work. Empirical rules for predicting press forces using forming tool design parameters and workpiece design and material properties do exist and have been evolving in past few decades [1, 3]. However, these rules did not include the effect of lubricants nor coatings on friction forces and as such are unable to predict the real press forces produced by coated tools. In order to highlight the 'true' benefit of coatings in metal forming the experiment trials are needed to be carried out.

2. EXPERIMENTAL PROCEDURE AND DATA PROCESSING OF FORMING FORCES AND PRESS WORK

Experimental investigations were carried out on a 50 tonnes hydraulic Ruwolt press using a specially designed multipurpose dieset equipped with a tool set for conducting both drawing and redrawing operations. In drawing operation, the 60mm diameter and 1mm thick blanks were drawn to cups with the height of 22mm and internal diameter of 32mm. In redrawing operations, these cups were reduced to the finished height of 30mm and diameter of 25mm. Investigated were TiAlN (PVD) and TiN (PVD) coated forming tools. The same tools were also tested in uncoated conditions for comparison purposes. The punch corner radius was 5mm and the die entry corner radius was 3mm for both deep drawing and redrawing operations. The workmaterials formed were 1010 steel and 1200 aluminium.

The forming tests involved production of 45 cups. 15 cups were made by uncoated and 15 cups each were made by the TiAlN and TiN coated tools. The deposition of TiN was after conducting tests with TiAlN coated tools which were stripped off the coating and recoated with TiN for further testing, in order to have the same tool (geometry) for the experiments. In total, 45 drawing tests and 45 redrawing tests were run for this study.

During drawing and redrawing trials the actual press force and stroke for each operation and workpiece material combination were recorded using a force and displacement recording equipment fitted on the press and connected to a computer. The forces were measured directly from force stroke out puts. The press work was calculated as an area under the force-stroke curve.

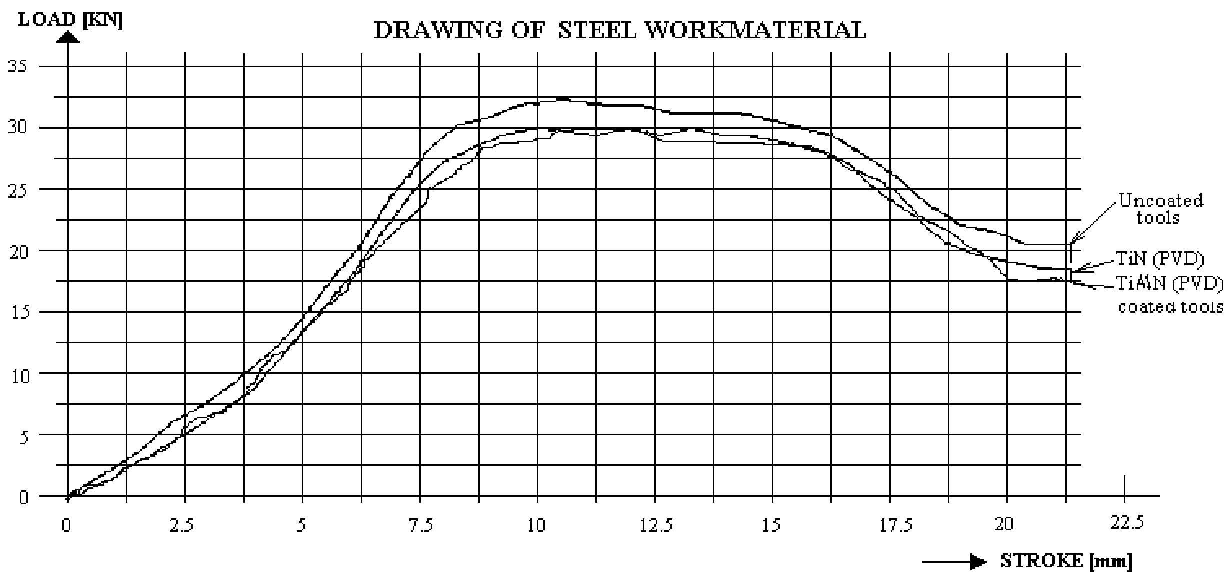
The experimental data associated with the forces and press work data for uncoated and coated tools were then compared using statistical tests and Excel software®. The statistical comparison of variances (Fisher test) was used for determining the homogeneity of variances. The t-test and/or Welch test for homogeneous and/or non homogeneous variances, respectively, was used to compare the means for each set and quantity. The comparison was first carried out for the coated tools *i.e.* TiN versus TiAlN. They were found to yield statistically similar quantities so they were treated as one group and the further statistical comparison was conducted between the tools in coated and uncoated conditions.

Where the differences were found to be statistically significant, the percentage deviation between each quantity, such as forces and press work, for the coated and uncoated tools for each pair of corresponding forming conditions were evaluated using Equation 1.

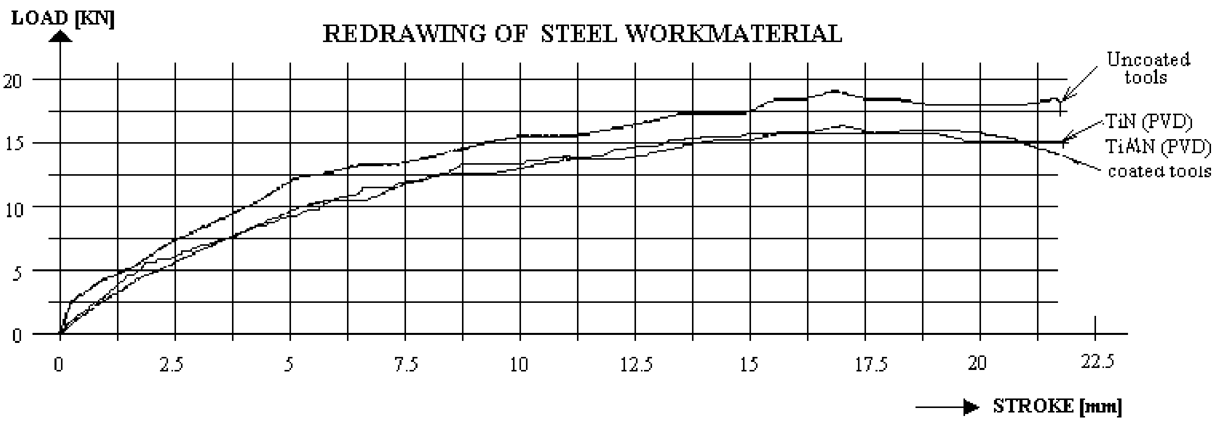
$$\%dev = \frac{[F, or, W(coated) - F, or, W(uncoated)]}{F, or, W(uncoated)} x100 \quad (1)$$

3. RESULTS AND DISCUSSION

Figure 1 shows typical 'as measured' load/stroke out puts produced by uncoated and TiN (PVD) and TiAlN (PVD) coated tools when a) drawing and b) redrawing 1200 aluminium workmaterial. Another Figure 2 shows the load/stroke out puts for 1010 steel workmaterial. It is evident from both these Figures 1 and 2 that the coated tools produced lower forces, and hence lower press work, than the uncoated tools.

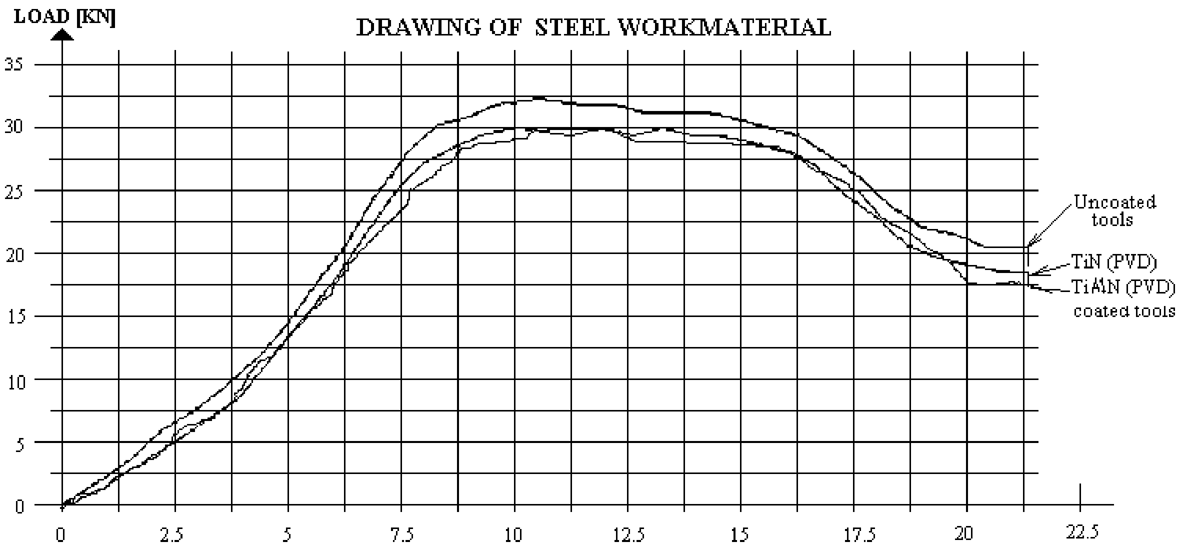


(a)



(b)

Figure 1 Load/stroke out puts showing comparison of forces produced in drawing and redrawing 1200 aluminium blank work piece material using uncoated and TiN (PVD) and TiAlN (PVD) coated tools.



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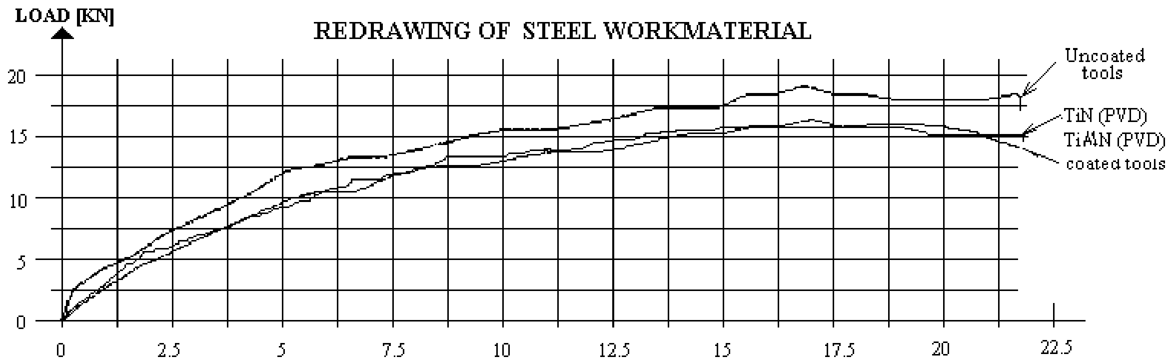

(b)

Figure 2 Load/stroke out puts showing comparison of forces produced in drawing and redrawing 1010 steel blank work piece material using uncoated and TiN (PVD) and TiAlN (PVD) coated tools.

The experimental forces and press work for coated and uncoated tools have been statistically compared. It was found that the mean values of forces in drawing and redrawing were statistically different, at 95% and higher confidence level, for both the coated tools and the uncoated tools. The same was found for the press work. This allowed to use the common grand mean values for forces and press work and to calculate the overall benefit of coated tools against uncoated tools, as shown in Table 1 for 1200 aluminum workmaterial, and in Table 2 for 1010 steel workmaterial.

From Tables 1 and 2 it is evident that the coating was responsible for large percentage reductions of the forming forces and press work for both workmaterials tested. Referring to Table 1, from quantitative point of view, the overall reductions were close to -9% for drawing forces, and around -22% for redrawing forces, -9.6% for drawing press work and -25 for redrawing press work when forming 1200 aluminium workmaterial. Referring to Table 2, from quantitative point of view, the overall reductions were very close to -6% for drawing forces, -16% for redrawing forces, about -7% for drawing press work and close to -20% for redrawing press work when forming 1010 steel workmaterial. From this it is evident that the reductions for forces and press work in redrawing operations were two-three times larger than in drawing operations. Hence, the benefit of coating appears to be more significant in redrawing than in drawing. Consequently it is expected that this will have positive effect on the final product quality.

Table 1 Experimental forces and press work with corresponding quantitative benefits of TiN (PVD) and TiAlN (PVD) coated tools over uncoated tools in drawing and redrawing 1200 aluminium workmaterial.

1200 aluminium workmaterial	Grand mean value of Forces [kN]		Average overall benefits of Coating in %	
	Drawing	Redrawing	Drawing	Redrawing
Uncoated tools	13.75 (±0.48)	7.45 (±0.33)	-8.9	-22.1
TiN coated tools TiAlN coat. tools	12.50 (±0.15) 12.1 (±0.18)	5.80 (±0.15) 6.2 (±0.12)		

1200 aluminium workmaterial	Grand mean value of Press Work [kNmm]		Average overall benefits of Coating in %	
	Drawing	Redrawing	Drawing	Redrawing
Uncoated tools	216.38 (±5.32)	161.31 (±2.37)	-9.5	-24.9
TiN coated tools TiAlN coat. tools	195.18 (±1.33) 194.98 (±1.63)	120.30 (±1.58 121.40 (±1.72)		

Table 2 Experimental forces and press work with corresponding quantitative benefits of TiN (PVD) coated tools over uncoated tools in drawing and redrawing 1010 steel workmaterial.

1010 steel workmaterial	Grand mean value of Forces [kN]		Average overall benefits of Coating in %	
	Drawing	Redrawing	Drawing	Redrawing
Uncoated tools	32.18 (±0.94)	19.37 (±1.34)	-5.8	-15.9
TiN coated tools TiAlN coat. tools	30.2 (±0.65) 29.8 (±0.55)	16.25 (±0.46) 17.15 (±0.65)		

1010 steel workmaterial	Grand mean value of Press Work [kNmm]		Average overall benefits of Coating in %	
	Drawing	Redrawing	Drawing	Redrawing
Uncoated tools	524.17 (±2.86)	248.43 (±4.68)	-6.8	-19.7
TiN coated tools TiAlN coat. tools	485.58 (±0.82) 489.63 (±0.99)	196.40 (±0.59) 195.80 (±0.69)		

4. CONCLUSIONS

- Pattern of forming forces, and hence press work, produced by the uncoated and the TiN (PVD) as well as TiAlN (PVD) coated tools tested in these forming experiments showed qualitative agreement and quantitative differences.
- When comparing the effects of different coatings TiN (PVD) and TiAlN (PVD), one with another, the quantitative differences in various performance measures namely forces and press power were statistically equal at 95% confidence level *i.e.* there were no qualitative on quantitative differences between these two coatings.
- In drawing 1200 aluminium workmaterial, the coated tools reduced forces by about -8.9% and work by about -9.5%. In redrawing the same workmaterial, the overall reductions in forming forces were -22.1% and in press work were -24.9%.
- In drawing 1010 steel workmaterial, the coated tools reduced forces by about -5.8% and work by about -6.8%. In redrawing the same workmaterial, the overall reductions in forming forces were -15.9% and in press work were -19.7%.
- The coated tools produced less scatter in the experimental forces and press work than uncoated tools.
- The highest reductions in forming forces and press work were in the final stage of drawing.

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