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DETERMINATION OF DRAWBEAD CONTACTS WITH VARIABLE BEAD PENETRATION

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Abstract

In stamping operations, the sliding of the sheet metal over the drawbeads is of great importance. The geometry of the drawbead and the degree of penetration both influence material flow and alter the frictional effects between the work and the tool. The effect of drawbead penetration over drawbeads has been studied using the Drawbead Simulator (DBS) test. The contact phenomenon between the sheet and drawbeads was analysed by examining deformed samples with an image fitting technique. The results were compared with an FE simulation and with an approximate geometric analysis. The results give a useful relationship between the rates of change of the contact angle with increasing bead penetration.

Key words: Sheet metal forming, drawbeads, penetration, conformity

1. INTRODUCTION

In commercial sheet metal forming the blank holder is used to develop resistance between the strip and the flange surfaces of the die to generate the required tension in the sheet for forming over the punch. In flat binders tension is governed by friction and lubrication; but in most industrial stamping processes the friction at the flat binder is not sufficient to control the metal flow over the punch towards the die cavity. Therefore, drawbeads are placed in the flanged section to overcome this problem with the most common shape in draw die process being beads with semicircular cross sections.

A drawbead is said to be fully penetrated when the sheet metal completely conforms to the geometry of the bead. In this situation with semi-circular beads, the strip covers the total of 360° angle of wrap around the male and female beads and the *intermesh thickness* is said to be the total penetration, which is equal to the sum of male and female bead radii and the sheet thickness. In this configuration the sheet undergoes the maximum deformation and the frictional forces are highest because the sheet is sliding over the entire bead surface.

In most real forming applications partial penetration of drawbeads occur and the wrap of the sheet metal does not reach 360°. Hsu et al. (2000) have explained the need to control the bead penetration to generate the required sheet tension. For a partially penetrated bead, the frictional forces are reduced and the bending energy may also be smaller. The bending energy is reduced when the radius of the curvature of the sheet metal is greater than the tooling radius and the sheet is no longer constrained to conform to the bend radii. The friction is reduced due to the reduction in both the amount of surface contact and the strip tension (Tufekci et. al., 1994).

In the current work an experimental draw bead simulator (DBS) was used to study the behaviour of the sheet in terms of the contact with the surface of the drawbeads for different geometries. These results

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were then compared with finite element and analytical models to assess their accuracy.

2. EXPERIMENTAL METHOD

The DBS test is designed to simulate the behaviour of the drawbeads in sheet metal flow stamping. The experiments were carried out at BlueScope Steel Research Laboratories in Port Kembla, Australia. The DBS rig was mounted on the crosshead of a hydraulically driven Instron test frame. Conventional DBS experiments are performed with two configurations, one with freely rotating roller beads and the other with the beads fixed. Only the fixed bead results are included in this work since the conformity in the partial penetration beads is different in fixed beads from that in freely rotating beads at the same penetration. The penetration depth of the draw beads could be controlled with this rig and the penetration was measured with the aid of a dial gauge mounted on the test frame.

The testing procedure consists of two steps: first the male bead penetrates horizontally to a predefined depth pushing the sheet metal strip through the matching groove into the female beads. The amount of bead penetration is determined by the depth of movement of the male bead into the sheet surface. Then, the sheet metal strip is pulled through the bead and into the die cavity. The experiments were performed for a range of penetrations from zero to full penetration with 9.5 mm diameter semicircular beads made from K245 tool steel. A standard clearance of t + 0.77 mm (where t is the sheet thickness) between the beads and the sheet strip was maintained during the test. The main purpose of this clearance is to prevent locking of the sheet between the beads.

DBS samples were analysed with a simple image fitting technique to determine the bend profile and the angle of conformity. Images of the cross section of the deformed samples were captured with a digital camera and fitted with the bead profiles with appropriate penetration geometries. A similar, but in-situ method was used by Green (2001) in his experimental work on drawbead behaviour. The contact angles were measured for a number of replicate samples with enlarged figures and the average angle was taken as the representation of the conformity for a given penetration. table 1 describes the details of the measured strip profiles.

Table 1. Measured Strip Profiles

Profile	Description
Entry	Wrap of the strip around the female bead at entry side (top) of the draw bead set-up. The free end of the strip was kept vertical with the support of a set of guide rollers
Half centre	Half of the total conformity of the strip around the male bead
Exit	Wrap of the strip around the female bead at exit of the draw bead set-up, the pulling force retains the strip vertically

3. THE FINITE ELEMENT MODEL

ABAQUS CAE version 6.4 was used for the FE modelling of draw beads. A 2D FE model was used in the analysis; the FE model also consists of two steps. In step 1, the binder moves horizontally through the meeting grove between the female beads to give the required penetration level. Step two involved the pulling of the strip vertically downwards at a constant speed and in this study, the speed was maintained at 50 mm/s. The beads are modelled to have two different configurations, free and fixed. The bead contact conditions and forces were determined with respect to fixed beads, as in the experiments. The FE and experimental analysis are interrelated because the coefficient of friction values from experimental analysis were used for the contact analysis in FE modelling.

4. GEOMETRIC INTERPRETATION

The average quarter contact angle θ can be determined for the different geometries by FE simulation and experimental methods. The most basic model is with the assumption of perfect geometric contact and conformity around the roller. Here, the main assumption is that the unsupported segments are straight and, therefore, the angle of θ can be represented as,

$$\theta = \frac{\pi}{2} - 2\alpha \tag{1}$$

The angle θ is represented with respect to an angle, α, which has a direct relationship with the geometry of the set-up and also a function of the bead penetration, p, as shown in Figure 1.

$$\tan\alpha = \frac{2r + t - p}{2r + t + s} \tag{2}$$

where: r – radius of the male/female bead, t – sheet thickness, p – penetration, s – shim (0.77 mm for 0.80 mm sheet thickness) c – side clearance (per side is equal to $t + s$)

When $p - t = 2r$, θ will be $\pi/2$ confirming the full penetration and this can be obtained when $p = 10.3$ mm for a sheet thickness of 0.8 mm. In this work, it is assumed that the radius of bending curvature, $\rho = r$, although, as mentioned, this assumption does not appear to be valid for small penetrations.

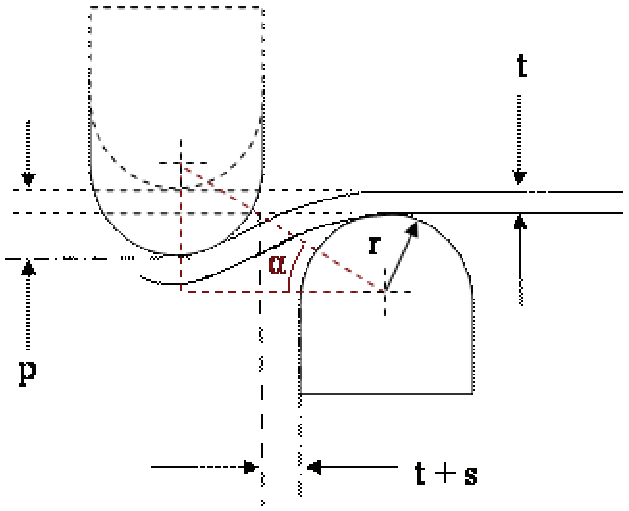


Figure 1. Schematic for the angle measurement for degree of penetration

5. RESULTS AND DISCUSSION

The variation of the experimental and FE contact angles are shown in Figures 2 and 3, respectively. The average conformity (quarter of the total wrap) around the male and female beads is calculated and compared with the geometrical and FE models. Since the experimental angles were determined after deformation, the strip profiles could have been affected by spring back and elastic recovery. It was noticed that within the tooling the conformity is slightly greater than the unloaded conditions where the angles recorded in the experiments were measured.

Several important characteristics of the draw-beads were observed from the experimental and FE simulations, and in particular the development of contact around the draw beads. It was observed that there is a clear correlation in the angle of conformity for the experimental and finite element results, especially at deep penetrations.

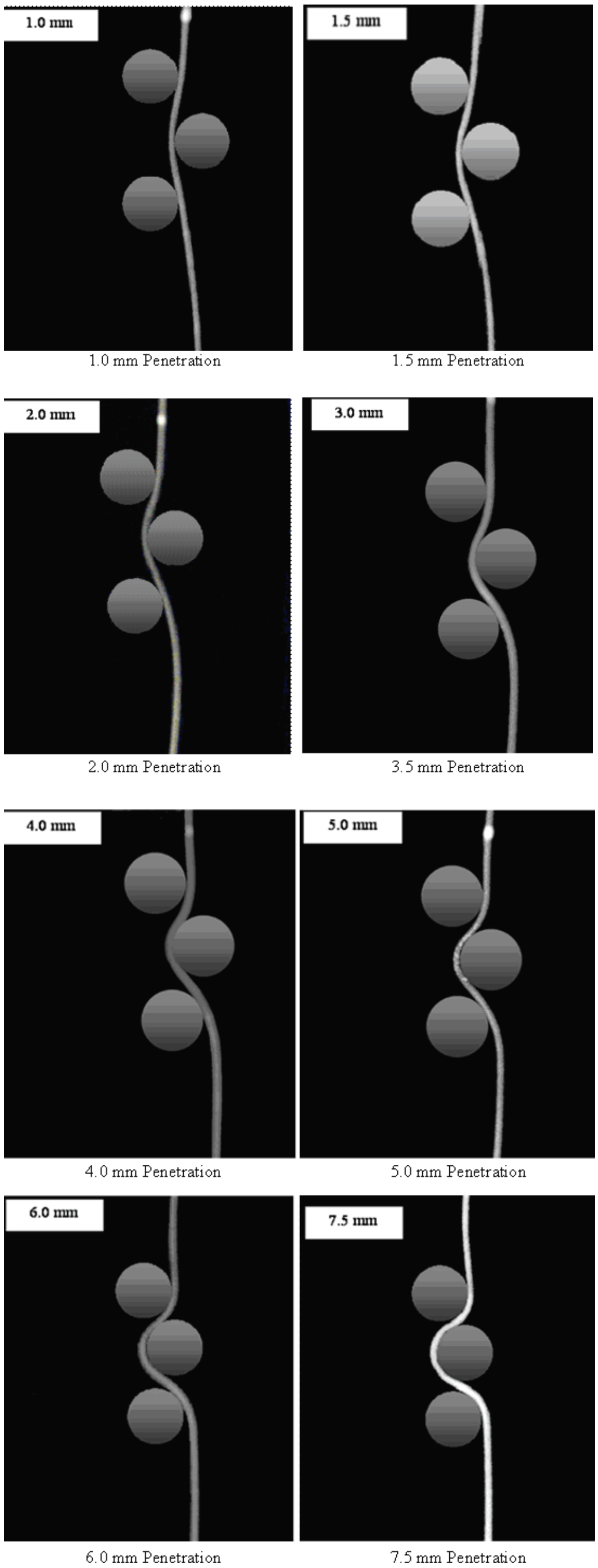
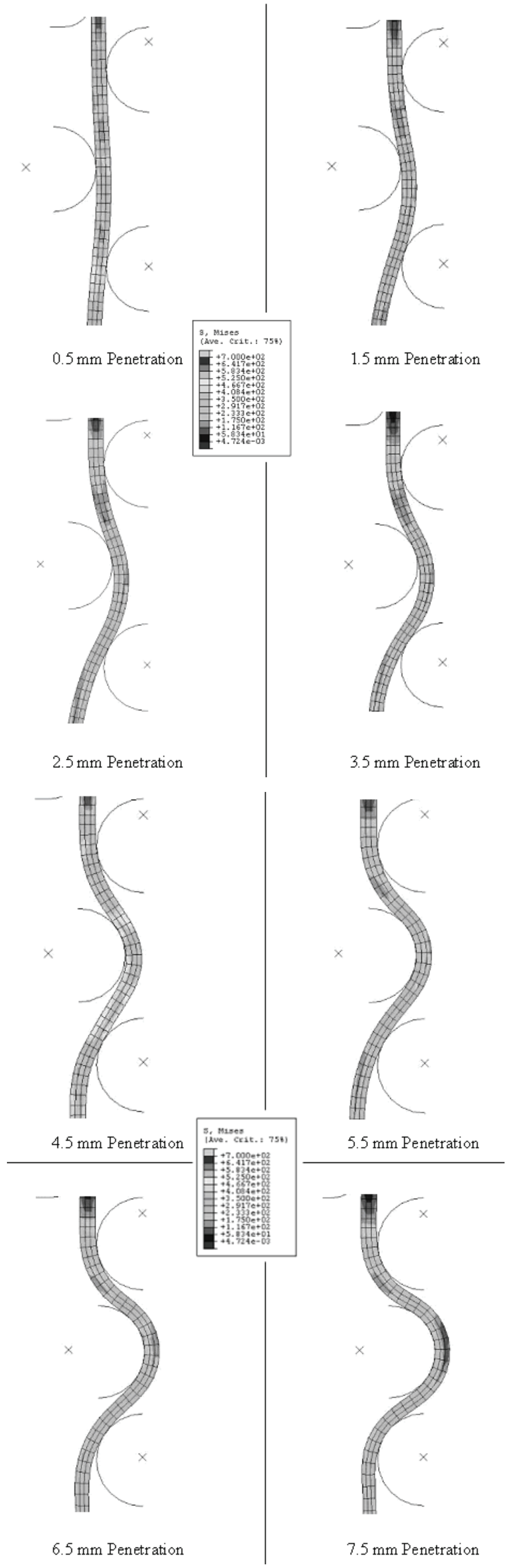


Figure 2. Experimental Bead Profiles



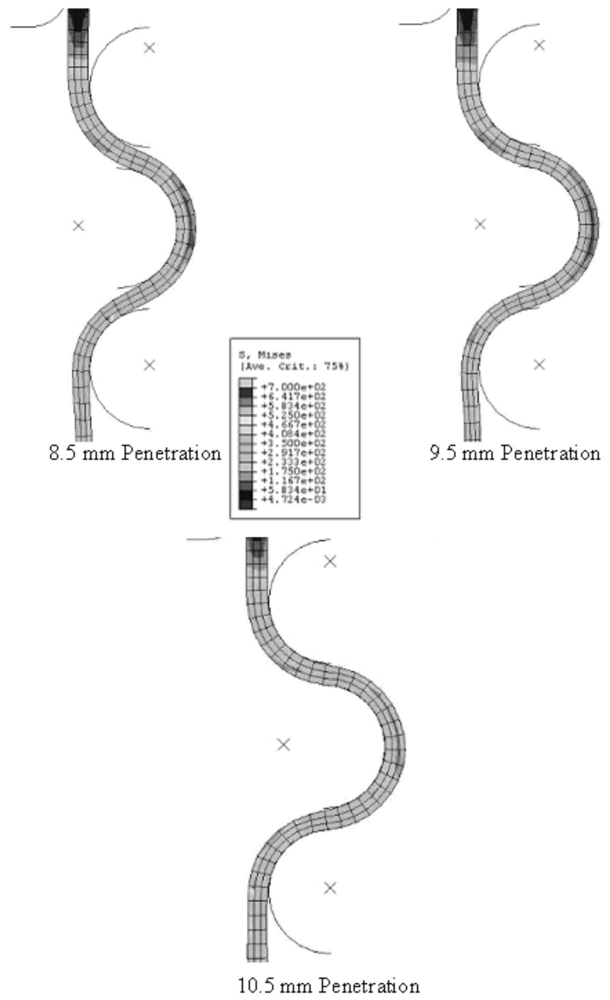


Figure 3. Bead Profiles in FE Simulation

In the geometric approximation, it was assumed that angles at the exit and entry side of the bead set-up are similar to each other. However, in both FE and experimental work, non-symmetric contacts were observed around the male bead as shown in Figures 2 and 3, where there is a considerable difference in the entry and exit conformity. The contact angle was greater at the entry side than at the exit side of the male bead, but the difference diminishes once half of the full penetration is achieved. The contact angles calculated with experimental and finite element simulation are presented in Figures 4 and 5, respectively.

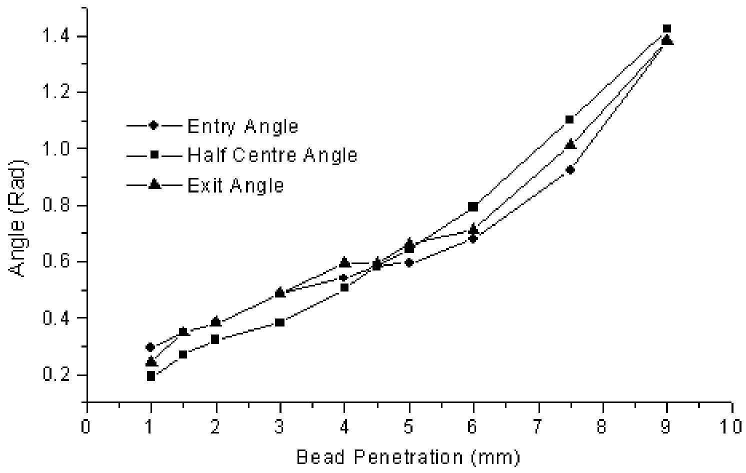


Figure 4. Experimental Angle of Conformity around Male and Female Beads

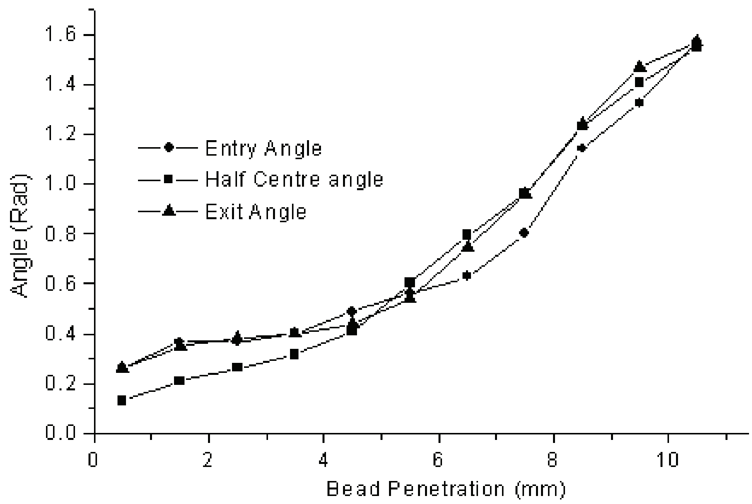


Figure 5. Angle of Conformity in FE Model around Male and Female Beads

The rate of increase of the contact is not linear. The angles (at the entry, half centre and exit) increase at a lower rate with increasing penetration until below half the full penetration (Fig. 5). Green (2001) has found that the bend radius decreases exponentially with increasing bead penetration; it was also shown that the angles at the entry, exit and the centre fall in a similar way. Green (2001) did not present any results for penetration less than 20% of the full penetration, where the bead contact is similar to a point contact. In this work it was observed that the half centre contact angle is always smaller than the entry and the exit angles below half of the full penetration. When the penetration increases beyond half of the full penetration, the half centre contact angle was observed to increase over the exit or entry angles.

The geometric interpretation of conformity is based on several assumptions and approximations. It was assumed that the radius of curvature to thickness ratio (ρ/t) is a constant, but during deformation, the ρ/t ratio decreases slightly due to thinning and a decrease in the bending forces. For very low penetrations, the radius of curvature of the strip was observed to be much higher than the bead radius and the geometric approximation is invalid. Green (2001) using an imaging technique, found that at shallow penetrations, the bend radius of the strip over the entry shoulder radius was significantly larger (5-6 times larger) than the bead radius and the strip typically made contact with the bead only at one point. This is an agreement with the experimental and FE observations in this study. FE profiles and the experimental strip profiles clearly show that the bead radius is much smaller that the strip radius. The ratio of bend profile radius to bead radius varies with penetration as well as during sliding.

The geometry of the sheet profile around the bead depends on several other factors including the rigidity of the sheet strip or the resistance for bending and elasticity, and, therefore, depends on the moment of inertia of the cross section. The thickness reduction of the sheet influences the deformation mechanics and friction and the assumption of constant thickness also leads to an increased uncertainty in the results. The conformity which was calculated with the geometric assumptions given showed a linearly increasing pattern. The relation derived for contact angle, equation 1 and equation 2, converges to a complete 360° contact around male and female beads, but experimentally it is not possible to achieve this when a clearance is present between the sheet and the beads. During very shallow penetration, the strip shows characteristics closer of that of a point contact and at such shallow penetration, the assumed geometric contact is not achieved.

5.1. Change in the Dynamic Contact Angle

After the male bead protruded through the female bead deforming the sheet, a certain contact angle is generated around the male and female beads. This contact angle does not remain constant during the drawing process. A number of important characteristics were observed in the change in the contact angle. The centre contact (around the male bead) increases when sliding starts; however, the exit and entry contact decreases since tension is being developed in the unsupported segments.

Although a continuous contact of the strip is expected, the half centre angle does not represent the full conformity around the bead at higher bead penetrations. During the start of drawing, discontinuation of the bead contact was observed over the male bead when the penetration exceeded 6.0 mm. The separation facilitates the entrapment of oil film between the surfaces and alters the frictional pattern. Higher contact pressure at the exit and entry to the bead also contribute towards this complicated frictional behaviour. Trapped lubricant due to strip separation over the bead surface also enhances the separation of metal to metal contact at the top of the bead possibly giving rise to hydrodynamic lubrication. At the same time, due to high pressure against the sheet at entry and exit points, considerable surface wear was observed in the DBS samples supporting metal to metal contact. It can be suggested that at exit and entry points, the strip-bead system behaves according to boundary lubrication. Therefore, non-flat lubricated contacts with variable pressure distribution may not represent the lubrication regimes according to the Stribeck Curve. What was observed as frictional forces in such situations are the combined effects of all the low and high pressure friction prevailing in different contact areas. This situation ceases when the drawing progresses; a continuous wrap of the sheet is observed around the beads.

5.2. Comparison of Contact Angles with Drawbead Penetration

Figure 6 shows a comparison of contact angles measured in the FE model and experimental work. It is seen that the geometric representation over estimated the contact angles. After half of full penetration, a clear turning point in the gradients from experimental and FE models was observed whereas the geometrical representation showed a more gradual change. The FE model showed that the contact angle increases with a smaller gradient until half penetration is reached and starts increasing rapidly after the penetration increases further. Experimental analysis shows similar results, but the difference between the initial and secondary gradients are smaller than the FE model.

At deep penetrations, the FE curve, experimental curve and the geometrical curve shows a similar pattern, but in terms of contact angles, experimental and FE angles are slightly smaller than the perfect geometric conformity. Overall, the average experimental, analytical and FE contact angles are similar except the penetrations around the half of the full bead penetration. The results further justify that complete geometric conformity cannot be experimentally achieved even at full penetrations, when a clearance is present between the sheet and the bead.

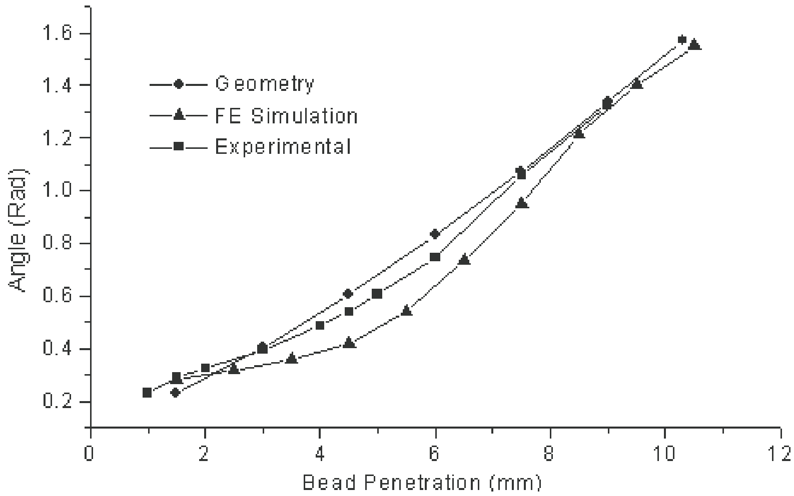


Figure 6. Comparison of Average Quarter Contact Angle

5.3. Effect of Bead Contact on Drawbead Friction

The main endeavour of the determination of the actual conformity was to relate the results with friction definitions in the DBS test. A widely accepted model for the coefficient of friction in the DBS test is given by (Nine, 1978),

$$\mu = \frac{1}{\pi} \frac{F(Pull)_{FixedBead} - F(Pull)_{RollerBead}}{F_C} \quad (3)$$

where F (Pull) $_{\text{Roller Bead}}$ is the pulling force in the roller bead test, F (Pull) $_{\text{Fixed Bead}}$ is the pulling force in the fixed bead test and F_C is the lateral force used for clamping in the fixed bead configuration with identical testing and geometric parameters. It was found that the angle of wrap that corresponds to the actual engagement of the strip with the roller or bead was not taken into account in the derivation by Nine (1978). Green (2001) states that, not until very deep penetrations does the tangent-to-tangent bead wrap assumption became approximately valid. Green's comments (2001) support the argument that the validity of the equation by Nine (1978) is applicable for complete penetrations. Later researchers (Green, 2001; Michler et. al., 1995; Stoughton, 1998; Tufekci, 1994) have discussed the issues of partial penetration and the material behaviour in partially penetrated drawbeads, but no mathematical model has been presented to calculate the coefficient of friction or the actual conformity.

In the previous work by the authors, it was shown that the friction in the DBS test may be presented as (Nanayakkara et. al, 2004),

$$\mu = \frac{(F_{fixed} - F_{free})}{F_C} \frac{\sin\theta}{2\theta} \tag{4}$$

where θ is the quarter contact angle of actual engagement of the strip over the bead. The conformity results in the current work can be related with the above mathematical model that enhances the accuracy in friction calculations. Therefore, the multiplication factor $\frac{\pi \ Sin\ \theta}{2\theta}$ can be used to convert the conventional coefficient of friction upon the change in conformity calculated in this work (Nanayakkara et. al, 2004).

6. CONCLUSION

The increase in the average contact angle with depth of penetration is less below half of full penetration and then increases rapidly until reaching full bead penetration. This is important since the actual coefficient of friction is a function of the angle of contact. The analysis presented appears to represent the process for partial penetration in an acceptable manner provided the bead depth is greater than about a half that of full penetration. The mathematical model was further developed to determine the exact contact angle to represent the conditions in drawbeads with shallow penetrations; especially for penetrations less than half of the full penetration. The deformation mechanics and the contact conditions were investigated with a series of bead penetrations from zero to 9 mm. A simple image fitting technique was used to determine the experimental conformity. A finite element model was also used to gain a clearer picture of the sheet conformity and the deformation mechanics.

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WYZNACZENIE STYKU PROGÓW CIĄGOWYCH I BLACHY DLA RÓŻNYCH WYSOKOŚCI PRZEGIĘCIA BLACHY

Streszczenie

Ślizganie się blach po progu ciągowym ma istotne znaczenie w procesach tłoczenia. Zarówno kształt progu jak i wysokość przegięcia blachy na progu mają wpływ na płynięcie metalu i mogą poprawiać warunki tarcia na styku odkształcanej blachy i narzędzia. Wpływ wysokości przegięcia blachy na progu ciągowym badano doświadczalnie na symulatorze progu ciągowego DSB (Drawbead Simulator). Zjawiska na styku między blachą i progiem ciągowym analizowano poprzez badania próbek metodą identyfikacji zarejestrowanego obrazu. Wyniki pomiarów porównano z obliczeniami metodą elementów skończonych oraz z odpowiednią analizą geometryczną. W konsekwencji wyznaczono przydatną zależność pomiędzy prędkością zmian kąta styku i wzrostem wysokości przegięcia blachy.

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