INVESTIGATION OF NON-UNIFORM THICKNESS SECTION EFFECT ON TWIST SPRINGBACK BEHAVIOUR

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by

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AA	Aluminium Alloy
BHF	Blank Holder Force
BIW	Body In White
CCD	Charged-coupled Device
CMM	Coordinate-measuring Machine
DA	Displacement Adjustment
FE	Finite Element
FEM	Finite Element Method
GBSC	Geometry-based Springback Compensation
HSS	High Strength Steel
MBSR	Mechanics-based Springback Reduction
TRB	Tailor Rolled Blank

LIST OF SYMBOLS

%	Percentage
$\Delta\varepsilon_x$	Change in strain
$\Delta\theta$	Springback value
CO_2	Carbon dioxide
E	Young's modulus
e	Engineering strain
E'	Plane strain modulus
K'	Strength hardening coefficient
K_s	Springback factor
r	Radius of curvature
R	Average anisotropy coefficient
r'	Radius after springback
R_f	Final bend radii
R_i	Initial bend radii
T	Sheet thickness
Y	Yield strength
α_f	Bend angle after unloading
α_i	Bend angle before unloading
σ_x	Stress
ε_t	Thickness strain

ε_w	Width strain
ε_x	True strain
θ	Bend angle
θ_f	Angle after unloading
θ_o	Angle after loading

KAJIAN KESAN BAHAGIAN BERKETEBALAN TIDAK SERAGAM TERHADAP TINGKAH LAKU KILASAN BIDAS-BALIK

ABSTRAK

Pada masa kini, pengeluar automotif menghadapi cabaran utama seperti peraturan yang semakin ketat di banyak negara dan persaingan untuk mengeluarkan kenderaan yang jimat bahan api. Isu-isu ini dapat ditangani dengan mengurangkan berat kenderaan dengan menggunakan komponen automotif dengan bahagian berketabalan tidak seragam. Bagaimanapun, bahagian logam yang dihasilkan menggunakan proses pembentukan mengalami bidas-balik, yang akan menghasilkan komponen yang tidak mengikut toleransi produk yang dikehendaki dan kilasan bidas-balik adalah antara yang paling sukar untuk diramalkan. Kebanyakan kajian yang lepas tentang pengukuran dan ramalan kilasan bidas-balik memberi tumpuan kepada bahagian berketebalan seragam, dan kajian pada bahagian berketebalan tidak seragam masih kurang. Bahagian berketebalan tidak seragam mengalami pengerasan ketegangan yang tidak sekata, menjadikan ramalan pada kilasan bidas-balik menjadi sukar. Dalam kajian ini, kita telah menyiasat kesan kilasan sudut, jenis bahan dan nisbah ketebalan pada beberapa jenis profil yang berketebalan tidak seragam. Proses pembentukan kilasan dimodelkan dalam perisian FEA komersial, ANSYS Workbench, dengan menggunakan prosedur analisis struktur statik. Simulasi pembentukan kilasan dilakukan pada profil rata, tirus, menangga, cembung dan cekung. Kaedah grafik digunakan untuk mengukur sudut kilasan bidas-balik dengan menggunakan perisian MATLAB. Keputusan telah menunjukkan bahawa dengan meningkatkan sudut kilasan akan mengurangkan kilasan bidas-balik, manakala nilai

nisbah ketebalan yang rendah akan meningkatkan kilasan bidas-balik. Selain itu, bahan dengan nilai modulus Young yang rendah dan kekuatan hasil yang tinggi akan meningkatkan nilai bidas-balik. Sebagai contoh, bahan Aluminium Alloy 6061, yang mempunyai modulus Young yang terendah berbanding dengan bahan lain yang dipilih, memperoleh nilai bidas-balik tertinggi. Kesimpulannya, semua faktor yang dipilih mempunyai kesan yang besar terhadap kelakuan bidas-balik. Faktor yang paling ketara ialah nisbah ketebalan, dan sudut kilasan menjadi faktor yang kurang ketara. Untuk pengesahan eksperimen untuk simulasi, hanya profil rata dan tirus sahaja yang dipilih. Perbandingan antara simulasi dan eksperimen telah menunjukkan persetujuan yang baik untuk profil rata, membuktikan model simulasi boleh digunapakai. Walaubagaimanapun, beberapa perbezaan diperhatikan untuk perbandingan antara simulasi dan eksperimen untuk profil tirus. Perbezaan ini boleh dikaitkan dengan kesan pengerasan ketegangan dalam pengeluaran profil bahagian berketabalan tidak seragam (Merklein et al., 2014).

INVESTIGATION OF NON-UNIFORM THICKNESS SECTION EFFECT ON TWIST SPRINGBACK BEHAVIOUR

ABSTRACT

Nowadays, automotive manufacturers are facing major challenges such as the increasingly strict emission regulations and the competitive need to manufacture fuel-efficient vehicles. These issues can be partly addressed by reducing the weight of a vehicle by using automotive components with non-uniform thickness. However, stamped metal parts produced using forming processes experience springback defects, which would result in components that do not conform to the required product tolerances and twist springback is among the most difficult to predict. Past studies on the measurement and prediction of twist springback have mostly focused on uniform thickness sections, and studies on non-uniform thickness sections are still lacking. Non-uniform thickness sections experience uneven strain hardening, making the prediction of twist springback behaviour difficult. In this study, we have investigated the effect of twist angle, material type and thickness ratio of several types of non-uniform metal profiles. The twist forming process was modelled in a commercial FEA software, ANSYS Workbench, using a static structural analysis procedure. The twist forming simulations were conducted for flat, tapered, stepped, convex and concave profiles. A graphical method was used to measure the springback angle using MATLAB software. The results have shown that increasing the twist angle would decrease the twist springback, while a low thickness ratio value increases the twist springback. Additionally, material with a low Young's modulus value and high yield strength has a high value of twist springback. Example, the Aluminium Alloy 6061

specimen, having the lowest Young's modulus as compared to the other metals chosen, obtained the highest springback value. In conclusion, all the parameters chosen had significant effects on the springback behaviour. The most significant parameter was the thickness ratio, with the twist angle being the last influencing. For experimental validation of the simulation work, only the flat and tapered profiles were selected. Comparison between the simulation and experimentation have shown good agreement for the flat profile, proving the reliability of the simulation model developed. However, some variations were observed for the comparison between the simulation and experimentation of the tapered profile. This difference could be attributed to the strain hardening effect in the production of the non-uniform thickness section profiles (Merklein et al., 2014).

CHAPTER ONE

INTRODUCTION

1.1 Research Background

The world today is facing critical environmental challenges such as global warming and air pollution. A major contributor to these problems is the transportation sector. Although the transportation industry is an integral part of the global community, it is saddled with problems such as greenhouse gases emission, traffic, congestions and noise pollutions. The transportation sector contributes significantly to the economy of many developing countries, but at the same time, it is also the biggest offender for air pollutions and emissions (Caiazzo et al., 2013). The major segment of the transportation sector consist of road transport at 85.71%, followed by rail and air transportations at 14.05% and 0.24%, respectively (Ong et al., 2011). Fossil fuel consumption by the transportation industry results in emissions which are affecting the environment (Soylu, 2007). In particular, the emission of carbon dioxide (CO_2) is a major source of greenhouse gas pollution that is heightening the global warming phenomena (Leung et al., 2014). For every litre of burned gasoline, approximately 2.4kg of CO_2 would be released to the environment (Mahlia et al., 2010).

To address these environmental crisis, governments around the world are imposing more stringent policies to the automotive industry. In addition to these environmental requirements, the automotive industry is also striving to produce vehicles which are more fuel efficient, better performing and with improved safety features. Several strategies have been adopted to meet these criteria such as reduction of vehicle body mass, introduction of hybrid technologies, downsizing of engines and installation of turbocharging components (Leduc et al., 2003). Weight reduction is the most challenging task due to safety and comfort issues. Improving safety and comforts would lead to increase in vehicle weights as additional components or features are added (Allwood, 2012). However, weight reductions can directly improve the fuel consumption and reduce gaseous emissions. By reducing vehicles weight by about 100 kg, fuel consumption decreases by 0.35 litre/100 km, improving the fuel efficiency by 8 %. CO_2 emission is also reduced by up to 8.4 g/km (Goede et al., 2009; Joost, 2012). Thus, weight reduction strategy is the most cost-effective method to reduce fuel consumption and greenhouse gas emissions from an automobile (Ghassemieh, 2011; Mayyas et al., 2012).

Body in white (BIW) structure accounts for approximately 25% of the total weight of a vehicle (Duan et al., 2016). Any weight reduction strategy must not compromise the vehicle safety and crashworthiness effect. The most common approach to reduce weight is by reducing part thicknesses or downsizing the size of the vehicle. However, these strategies may affect the strength of the vehicle structure and reduced vehicle stability for the occupants, increasing the health and safety risks of both the driver and passengers.

Tailor rolled blanks (TRB) are sheet metals with non-uniform thickness profile in a single metal sheet (Merklein & Opel, 2010). It is produced using rolling processes and is one of the technologies developed to reduce the weights of stamped components but at the same time maintaining the strengths of the developed structure. TRB have better surface quality because there are no weld seams and have good formability properties as no stress peaks are generated due to sudden thickness transitions (Merklein, 2014). The non-uniform blank thicknesses vary the material properties because of the variations in the strain hardening characteristics. However, this results in non-homogeneous springback behaviour in the material. TRB minimise deflection and a considerable high weight reduction of up to 13.5% can be obtained as compared to conventional uniform roll blanks (Merklein et al., 2014). In addition, structures made from TRB have outstanding crashworthiness characteristics (Duan et al., 2016). Typically, the cross-sectional profile of the strip can be produced using a profile roll performed parallel to the rolling direction of the blank, as shown in Figure 1.1 (a). A flexible rolling process, as shown in Figure 1.1 (b), is usually used in the industry to produce sheet metals with non-uniform sheet thicknesses.

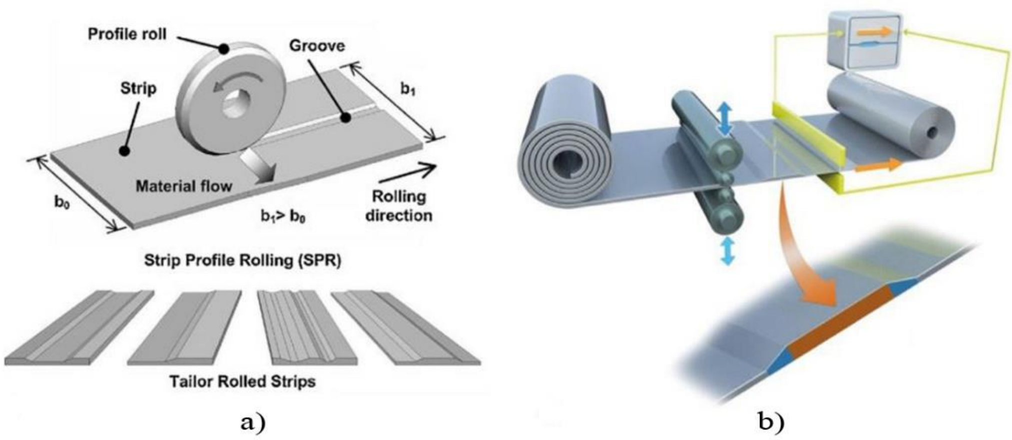

Figure 1.1. (a) Rolling process for longitudinal thickness variation, (b) Strip profile of flexible rolling process for latitudinal thickness variation (Merklein et al., 2014)

Parts and components with non-uniform thickness would behave differently as compared to parts with uniform thickness, due to strain hardening. Zhang et al. (2012) have found that the springback at the thinner side is larger than at the thicker side. The springback decreases as the thickness transition zone length increases due to the change of material properties in the rolling direction. In a study of high strength steel (HSS) stepped-shaped car bumpers, Ohwue et al. (2003) have found that the yield stresses have a significant influence on the springback behaviour. Zhang et al. (2010) have proposed a compensation method for concave and convex profiles to take into account the effect of springback in the production of HSS B-pillar automotive parts. It was generally found that as the thickness profile decreases, the springback would increase.

Springback can be categorised into three groups; flange springback, wall springback and twist springback (Dezelak et al., 2014). Generally, uncontrolled springback is considered as a defect (Wiebenga et al., 2013). Severe springback may affect the accuracy of mating parts as the springback can bring undesirable shape changes, leading to difficulties in assembly, a decrease in the material properties and causes geometrical unsuitability and unreliability of sheet metal after forming (Dezelak et al., 2014; Jiang et al., 2013). Studies on springback for uniform sections are widely documented, and numerous approaches have been proposed to compensate for this problem, either by experimental as well as simulation-based evaluations (Dezelak et al., 2014; Li et al., 2011; Sulaiman et al., 2012; Vorkov et al., 2014; Xue et al., 2015). However, the springback behaviour of non-uniform thickness section are not as widely studied. One recent example is the study conducted by Adnan et al. (2017) on the effect of geometrical profiles on the springback behaviour of aluminium strips with various thickness changes pattern such as tapered and convex profiles. Optimization of parameters, such as bend angle, thickness ratio and alignment of the workpiece during the experiment were made using Analysis of Variance (ANOVA) technique.

Twist springback behaviour is said to be more complex and differs from the common springback responses that are observed in flange and wall springbacks (Xue et al., 2015). Twist springback occurs immediately after a twist forming and twist bending process. It is characterised by the tendency of the twisted part return to its original shape due to the elastic recovery of the angle of twist on the removal of the applied torque (Abdullah & Samad, 2014; Dwivedi et al., 2002). Twist springback is a result of torsional moments in the cross section of the workpiece and the different rotations of two cross-sections along the axis (Li et al., 2011; Xue et al., 2016). The unbalanced elastic-plastic deformation and residual stresses released in the deformed part produce torsional moments that cause twist springback (Liao et al., 2017; Xue et al., 2015; Xue et al., 2014). Unbalanced forces are present in unsymmetrical part after forming operation because of non-uniform deformation gradients. They also appear in symmetrical parts due to the sheet metal position, non-uniform lubrication, and damaged or badly designed draw beads. Such problems result in unequal material flow and may cause unpredictable twist springback behaviour (Dezelak eat al., 2014). This study proposes the evaluation of springback in twist forming of non-uniform thickness sections, as this is a topic that is currently not widely explored.

1.2 Problem Statement

Sheet metal forming is a major process in the manufacture of automotive parts. Twist forming is currently used to produce twist rail, S-rail, B-pillar and A-pillar enforced rail. However, the process prone to undesirable side-effects such as twist springback. Severe twist springback will cause deviation of the shape which would make subsequent component assembly difficult. It is known that the thickness of components is one of the most influential factor in its springback response. Furthermore, this problem becomes more complicated and difficult to predict if the thickness is not uniform. Cold forming of non-uniform thickness results in uneven