OPTIMIZATION OF V-BENDING OF ALUMINIUM AA6061 STRIP OF NON-UNIFORM PROFILE USING THE TAGUCHI METHOD

by

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LIST OF SYMBOLS

\$	Dollar
%	Percentage
$\bar{x}_i$	Mean of the angle of springback in the experiment
$\Delta\sigma_x$	Elastic unloading
x_{ij}	Percentage of springback in the experiment
σ_0	Flow stress in plane
σ_T	True stress (load/instantaneous area)
ΔM	Change in bending moment
°C	Temperature
µm	Micrometer
Al	Aluminium
cm	Centimeter
cm^2	Centimeter square
Cr	Chromium
Cu	Copper
dF_x	Internal forces in x-direction
d_z	Portion of considered thickness
E	Young's modulus (N/mm^2)
F	Ratio of the mean of square deviation
Fe	Iron
F_x	External forces in x-direction
g	Gram
K	Springback ratio

M	Bending Moment (N/mm)
Mg	Magnesium
Mn	Manganese
n	Strain hardening exponent
nm	Nanometer
P	Significant rate
R	Minimum bend radius
r	Anisotropic value
R_i	Bend radius
rpm	Rotation per minute
Si	Silicon
t	Thickness
T	Tensile strength (N/mm^2)
Ti	Titanium
V	Volume
V	Value
w	Width
X_i	Springback variable
Zn	Zinc
α	Profile angle
θ	Bend angle (°)
$\theta + \Delta\theta$	Bend angle after spring back
ρ	Radius of neutral fibre/neutral radius (mm)
$\rho + \Delta\rho$	Radius of neutral fibre after spring back (mm)
ϵ_e	Elastic deformation

ϵ_{pl}	Plastic deformation
ϵ_t	Thickness strain
ϵ_u	Uniform elongation
ϵ_w	Width strain

LIST OF ABBREVIATIONS

AA	Aluminium Alloy
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
BIW	Body-in-white
CI	Confidence Interval
DOE	Design of Experiment
DOF	Degree of Freedom
EPE	Electroplastic effect
FEM	Finite Element Method
FLB	Front Longitudinal Beam
GBSC	Geometry-Based Springback Compensation
HSLA	High strength low alloy steel
IFM	Infinite Focuse Machine
MBSR	Mechanic Based Springback Reduction
MPa	MegaPascal
MSD	Mean Square Deviation
MSE	Mean Square Error
NVH	Noise, Vibration, Harhness
OA	Orthogonal Array
PB	Patchworks Blanks
PP	Profile Projector
S/N	Signal Noise
SSD	Sum Square Deviation

SST	Total Sum Square
THTB	Tailored Heat Treated Blanks
TM	Taguchi Method
TRB	Tailored Rolled Blanks
TWB	Tailored Welded Blanks

PENGOPTIMUMAN LENTURAN-V BAGI JALUR ALUMINIUM AA6061 TIDAK SERAGAM MENGGUNAKAN KAEDAH TAGUCHI

ABSTRAK

Pengeluar automotif pada hari ini sedang melangkah maju ke arah pengeluaran kenderaan yang lebih ringan. Terdapat pelbagai teknik yang sudah diuji dan dilaksanakan bagi mencapai matlamat ini. Variasi ketebalan dijangka dapat menjadi salah satu daripada pendekatan yang efektif dalam mengurangkan berat komponen automotif. Kebolehbentukan komponen ketebalan tidak seragam merupakan salah satu daripada aspek yang seringkali dilepas pandang di dalam proses pembentukan komponen kenderaan, sejak ketebalan menjadi salah satu daripada parameter yang paling mempengaruhi kebolehbentukan. Proses yang tidak betul dan keputusan yang salah boleh membawa kepada kecacatan yang teruk dan salah satu yang diberi perhatian adalah bidasan. Bidasan ialah satu bentuk kecacatan yang biasa ditemui dalam pembentukan kepingan logam yang disebabkan oleh pemulihan elastik dan pengagihan semula tekanan dalaman semasa beban dilepaskan. Bidasan boleh ditakrifkan sebagai perubahan anjal dalam rupabentuk komponen semasa beban diangkat setelah proses pembentukan. Kesan bidasan yang menukar rupabentuk dan dimensi akan mewujudkan masalah utama dalam pemasangan komponen tersebut. Dalam kajian ini, nisbah ketebalan dan sudut lenturan menjadi parameter utama, manakala suhu penyepuhlindapan, arah gelekan dan penjajaran sebagai parameter tambahan yang dikaji. Parameter-parameter ini adalah merupakan parameter yang paling mempengaruhi tingkahlaku bidasan berdasarkan kajian literatur dan merupakan parameter yang relevan dalam pembuatan komponen automotif. Parameter optimal yang mempengaruhi bidasan kemudiannya dikaji secara statistik menggunakan kaedah

Taguchi. Tatasusunan ortogon L_{18} ($6^1 \times 3^4$) dengan tiga lajur dan lapan belas baris telah dipilih sebagai model yang sesuai dan digunakan dalam kajian ini yang terdiri daripada satu parameter mempunyai enam tahap dan empat parameter selebihnya mempunyai tiga tahap. Dua profil variasi ketebalan telah dikaji, profil linear dan profil parabola dan masing-masing diwakili oleh bentuk tirus dan melengkung. Berdasarkan keputusan yang diperolehi pada eksperimen bentuk tirus, mendedahkan bahawa parameter yang paling mempengaruhi bidasan adalah strok sebanyak 87.57% diikuti oleh nisbah ketebalan (2.94%), arah gelungan (1.89%) penjajaran (0.68%) dan suhu penyepuhlindapan (0.42%), dan, manakala hasil daripada eksperimen bentuk melengkung menunjukkan parameter yang paling mempengaruhi adalah strok dengan anggaran sebanyak 82.41% diikuti dengan nisbah ketebalan (2.60%), suhu penyepuhlindapan (2.30%), penjajaran (0.59%) dan arah gelungan (0.49%). Berdasarkan keputusan yang ditunjukkan, kesimpulan dapat dibuat bahawa sudut lenturan dan nisbah ketebalan merupakan parameter yang paling mempengaruhi tingkahlaku bidasan bagi jalur aloi aluminium dengan ketebalan yang tidak seragam. Gabungan optimum A3 B3 C3 D3 E2 bagi bentuk tirus dan A2 B3 C3 D3 E3 bagi bentuk melengkung boleh meminimumkan bidasan.

OPTIMIZATION OF V-BENDING OF ALUMINIUM AA6061 STRIP OF NON-UNIFORM PROFILE USING THE TAGUCHI METHOD

ABSTRACT

Automotive manufacturer are now producing ever lighter vehicles. Various techniques have been implemented to achieve this. Thickness variation is one of the effective approach in reducing weight. Formability of the non-uniform thickness section has been overlooked in the forming process of these parts. Improper process and incorrect decision may lead to severe defect and one of the main concerns is a springback. Springback is a common defect found in sheet metal forming which is mainly caused by the elastic recovery and redistribution of internal stress during unloading process. The effect of springback is to change the shape and dimension of the parts and can create major problem in the assembly. In this study, thickness ratio and stroke are two main parameters, followed by annealing temperature, rolling direction and alignment. Optimal parameters obtained using Taguchi Method where an L_{18} ($6^1 \times 3^4$) orthogonal array with three column and eighteen rows and one parameter with six level and the other four parameters with three levels. Two profiles of thickness variation have been studied, tapered and parabolic profiles. The results for the tapered profile revealed that most significant parameter is stroke which contribute 87.57% followed by thickness ratio (2.94%), rolling direction (1.89%), the alignment (0.68%) and annealing temperature (0.42%), and while the result for curved shape showed that the most significant parameter is lead by stroke with 82.41% contribution followed by thickness ratio (2.60%), annealing temperature (2.30%), alignment (0.59%) and rolling direction (0.49%). Based on the result, it can be concluded that bend angle and thickness ratio are the most significant parameter that

influence the springback behavior of the aluminium strip with non-uniform thickness section. The optimal combination of A3 B3 C3 D3 E2 for tapered shape and A2 B3 C3 D3 E3 for curved shape can result in minimum springback

CHAPTER ONE

INTRODUCTION

1.1 Research Background

Weight reduction is an important objective in automotive manufacturing, because of its influence on costs and gas emissions. Weight reduction must be done without compromising safety in the design of body-in-white (BIW) parts. The thinner parts must also possess high mechanical properties, satisfying the Crash Test Norms (Abdulhay et al. , 2011).

The automotive industry is facing challenges of reducing body weight, in order to address environmental concerns and improve collision safety. One potential solution to both these problems, namely, the use of stronger steels for car bodies, is gaining prominence. High-strength steels, with different strength levels, have been developed, to provide a wide selection of materials for different applications, according to the required function. Compared to other light-weight materials, high-strength steels are advantageous in terms of the costs, the availability of production facilities, and as such, they are used as the principal materials for body weight reduction and collision safety improvement (Takahashi, 2003). The use of high-strength steels, however, leads to forming problems. such as low elongation consequent to higher strength, which increases the risk of sheet breakage during sheet forming, and a higher yield stress, which causes dimensional defects (springback), wrinkles, and other problems (Burchitz, 2005). To cope with these issues, forming dies have to be adjusted many times during the trial process, which leads to increased die manufacturing costs and other technical problems.

In modern transportation engineering, lightweight construction is one of the central challenges. Lightweight construction is optimal if a lightweight material is used only in component areas where stresses appear, and if the material used is charged near yield stress (Kleiner et al., 2003). There are two types of lightweight construction. The first type of lightweight construction deals with the use of light materials. In this approach, the use of light materials ensures identical geometry for every workpiece while reducing the total component weight. The second type of lightweight construction deals with different design strategies, including the forming process (Girubha and Vinodh, 2012). A material's formability depends on many factors including its' thickness, its' properties, and the complexity of the formed part (Kleiner et al., 2003). These factors may result in defects, such as springback, which could lead to more frequent part rejection.

In recent years, the automotive industry has been making an effort to reduce the vehicle weight, in response to the global development trend, which is towards lighter, fuel-efficient cars, with greater resistance to collisions. There are several vehicle weight reduction approaches currently available in automotive manufacturing. One such method, namely, the hot stamping of high steels, can bring about significant vehicle weight reduction. Li et al. (2014) discussed the hot stamping of a door impact beam by high-strength steel. Hot stamping consists of three phases; the approach, the forming, and finally, quenching (Abdulhay et al., 2011). Figure 1.1 show the manufacturing process of the B-Pillar by using the hot stamping process. The automotive parts today by hot stamping process are numerous. Most of the parts have varied thickness, and shaping them requires a special process. A-pillars, B-pillars, roofs, rear bumper beams, and door beams, are examples of components produced using hot stamping. The manufacture of such components can be carried out by using either different variants of the conventional hot stamping process, or by utilizing tailored semi-finished products.

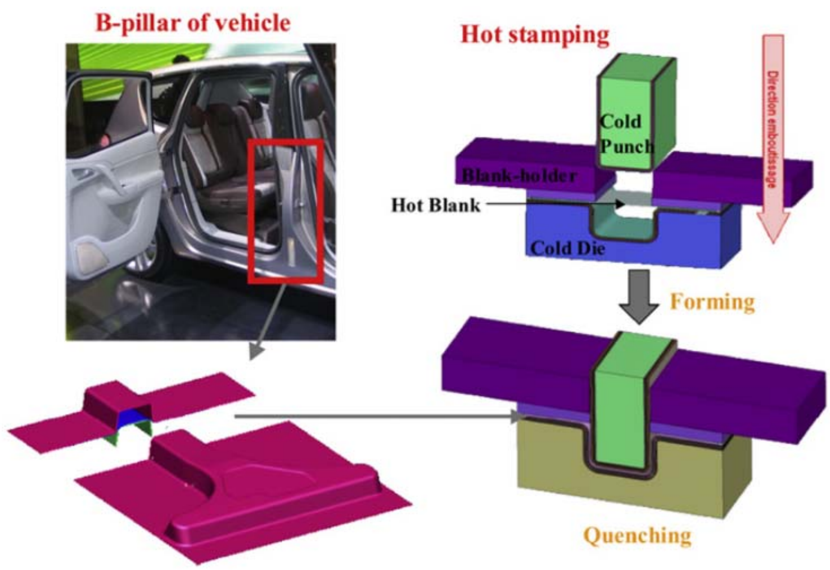

Figure 1.1. Manufacturing of a B-Pillar by using the hot stamping process (Abdulhay et al., 2011).

There are currently two main variants of the hot stamping process; the direct hot stamping method and the indirect hot stamping method. For the direct hot stamping process, a blank is heated up in a furnace, transferred to the press, and subsequently formed and quenched in a closed tool. The indirect hot stamping process can be by the use of a semi-complete, cold, pre-formed part, which is subjected only to the quenching and the calibration operations in the press after austenitization (Karbasian et al., 2010). Figure 1.2 show the schematic drawing of the direct hot press forming and indirect hot press forming. Lee (2009) in his study of automotive flex plate manufacturing by using the hot stamping process, stated that this process results in a significant increase in strength, and provides high dimensional stability.