Tailored and double-direction pressure distributions for vaporizing-foil forming

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“It is precisely the possibility of realizing a dream that makes life interesting.”

Paulo Coelho, Brazilian author

To my parents

For their love, patience, confidence and support

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Dortmund, January 2016 Sheng Cai

Abstract

Metal forming by vaporizing foils is an innovative impulsive forming method which requires no electrical conductivity of the workpiece and no expensive coils. The aim of this thesis is to develop innovative pressure distributions by vaporizing foils in order to improve the forming accuracy and the manufacturing productivity.

Firstly, the mechanical and physical processes of sheet metal forming by vaporizing foils are analyzed. Based on the analysis of the dynamic behavior of square plate and rectangular plate under impulsive loading, the final transverse displacement in the center of the plate can be predicted. In order to predict the shock pressure amplitude, an analytical model is developed which correlates the shock pressure and the process parameters which involve the bank machine, metal foil and the polyurethane plate.

Based on the analytical model, the process parameters are experimentally identified. With increasing the charging energy of the capacitor bank, the final shock pressure is improved while the increase of the foil thickness and width leads to a decrease on the pressure amplitude. Meanwhile, a thicker polyurethane plate is found to enhance the attenuation effect on the shock wave propagation resulting in a lower shock pressure.

With the knowledge of the process parameters, two different pressure distributions are developed which are the tailored pressure distribution and double-direction pressure distribution, respectively. The tailored pressure distribution can be generated by means of the combination of different process parameters such as foil length, width and polyurethane thickness and hardness. The double-direction pressure distribution resulted from the foil vaporization can provide the shock pressure both upward and downward at the same time.

Finally two application parts are manufactured by means of the developed new pressure distributions, respectively. The part produced using tailored pressure distribution demonstrates that this pressure distribution can greatly reduce the rebound effect in impulsive forming and manufacture the parts with different forming depths. The other part achieved from the double-direction pressure distribution indicates that this pressure distribution can be successfully used to profile forming.

Zusammenfassung

Metallumformung mittels Folienvaporisation ist eine neuartige Impulsumformtechnik. Der Prozess basiert auf der schnellen Verdampfung metallischer Folien durch sehr hohe gepulste elektrische Ströme. Infolgedessen bildet sich ein schnell expandierendes Plasma, durch das ein starker mechanischer Druckimpuls generiert wird. Über ein elastisches Polyurethankissen wird dieser Umformdruck auf das Werkstück übertragen und führt zu seiner plastischen Deformation. Im Vergleich zur elektromagnetischen Umformung, dem bekanntesten Hochgeschwindigkeits-umformverfahren, erfordert der hier betrachtete Prozess keine elektrischleitfähigen Werkstücke und keine komplexen Werkzeuge. Ziel dieser Arbeit ist die Realisierung maßgeschneiderter Druckverteilungen im Hinblick auf die gewünschte Bauteilform.So soll die Formgenauigkeit der Bauteile verbessert und die Produktivität des Verfahrens gesteigert werden.

Um diese Zielsetzung zu erreichen, wird im Rahmen dieser Arbeit zunächst ein grundlegendes Prozessverständnis der Blechumformung durch Folien-verdampfung entwickelt. Basierendauf analytische und experimentelle Untersuchungenwerden bedeutende Prozessparameter identifiziert und ihr Einfluss auf das Umformergebnis analysiert. Für die analytischen Untersuchungen wirdein Ansatz zum dynamischen Verhalten quadratischer beziehungsweise rechteckiger Platten unter Impulsbelastung mit einem hier entwickelten Modell zur Beschreibung der physikalischen Vorgänge bei der Folienvaporisation kombiniert. Neben der Identifikation von signifikanten Prozesseinflussgrößen, wie z.B. der Kondensatorladeenergie oder der Foliengeometrie, erlaubt dieser analytische Ansatz die Abschätzung des wirkenden Druckimpuls und der resultierenden Einformung in der Werkstückmitte.

Auf Grundlage des erlangten, grundlegenden Prozessverständnisses werden im Folgenden zwei neue Prozessvarianten entwickelt. Bei der ersten Variante wird die Druckverteilung über die Foliengeometrie beziehungsweise die Eigenschaften des Polyurethankissens lokal an die gewünschte Bauteilkontur angepasst.Das heißt, dass die Druckverteilung über die Umformzone in Abhängigkeit von der Tiefe der Werkzeugkavität variiert wird. So kann das bei der Impulsumformung in manchen

Bauteilbereichen auftretende Zurückprallen des Werkstücks vom Werkzeug unterbunden beziehungsweise reduziert werden.Als Ergebnis kann die Formgenauigkeit der Bauteile deutlich gesteigert werden.

Die zweite Prozessvariante, die im Rahmen dieser Arbeit entwickelt wird, ist die bidirektionale Umformung mittels Folienvaporisation. Hierbei werden mit einer verdampfenden Folie zwei Bauteile in entgegengesetzte Richtungen umgeformt.Hierdurch lässt sich die Prozesseffizienz signifikant steigern. Des Weiteren eignet sich dieser Aufbau auch zur Umformung von Profilen mitvor allem rechteckigem Querschnitt.

Table of Contents

Nomenclature

Symbols

Variable	Unit	Description
A	m^2	Cross section
B	mm	Semi-width of the rectangular plate
c	m/s	Gurney velocity
C	F	Capacity
C	m/s	Shock impedance
d	mm	Travel distance of shock wave
d_0	mm	Effective absorption depth of energy
E	J	Electrical energy
E_c	J	Charging energy
E_g	J	Electrical Gurney energy
E_k	J	Kinetic energy
g	A^2 s mm^{-4}	Action integral
H	mm	Bulging height
H	mm	Thickness
I	A	Current
I	-	Effective impulse work
I_m	A	Amplitude of current
j	A/m^2	Current density
J_B	A/ mm^2	Burst current density
L	H	Inductivity
l	mm	Length of active part
L	mm	Semi-length of plate

Variable	Unit	Description
m_f	kg	Mass of the foil
M	kg/ m^2	Mass per unit area of the flyer
M	N·m	Equivalent moment
M_0	N·m	Collapse moment
M_x	N·m	Bending moment about x axis
M_{xy}	N·m	Twisting moment
M_y	N·m	Bending moment about y axis
N	J/mm	Electrical power per unit length
N_f	kg/ m^2	Mass per unit area of the foil
p	MPa	Pressure
p_0	MPa	Impulsive pressure
p_1	MPa	Shock pressure at the travel distance
p_2	MPa	Pressure on workpiece
p_c	MPa	Collapse pressure
p_e	MPa	Effective pressure
p_m	MPa	Amplitude of pressure pulse
p_{max}	MPa	Maximum pressure
Q_0	Q	Charge of the capacitor
Q_x	N	Transverse shear force about x axis
Q_y	N	Transverse shear force about y axis
R	Ω	Resistance
R^L	MPa	Collapse load of the rectangular plate
s	mm	Thickness of sheet metal
S	mm	Transverse displacement

Variable	**Unit**	**Description**
S_f	mm	Final transverse displacement
T	s	Duration of response of a square plate
t	s	Time
t_0	s	Duration of the impulsive loading
t_b	s	Burst time
t_c	s	Time for yielding moment
t_f	s	Duration of response of a rectangular plate
t_{mean}	s	Interval between the onset of the plastic deformation and the centroid of the pressure pulse
t_r	s	Rise time of current
v	m/s	Velocity at positions on sheet metal
V	m^3	Effective volume
V	m/s	Velocity in the center of the workpiece
V	V	Voltage
V_1	m/s	Transverse velocity at the end of the pressure pulse
V_2	m/s	Final velocity of the workpiece
V_f	m/s	Velocity of the flyer
w	J	Specific deposited energy
x	mm	Position about x axis
y	mm	Position about y axis
α_1, α_2	m/s^2	Acceleration
ΔH_b	J /(kg·°C)	Specific heat
μ	-	Friction coefficient

Variable	**Unit**	**Description**
ρ	Kg/m^3	Density
ρ	$\Omega\cdot m$	Resistivity
ρ_{al}	kg/m^3	Density of aluminum
ρ_{pol}	kg/m^3	Density of polyurethane
ω	Rad/s	Angular rate
∂	-	Attenuation factor
ϕ	-	Deflection angle
δ_f	mm	Final transverse displacement in the center of the rectangular plate
Γ	-	Grüneisen coefficient
u	m/s	In-plane velocity
w	m/s	In-plane velocity
γ	-	Resistivity
ε_i	-	Strain component
σ_i	-	Stress component
σ_0	MPa	Yield stress

Abbreviations

Abbreviation	**Description**
PU	Polyurethane plate
PE-HD	Polyethylene in high density