العنوان:	Using finite element simulation to predict the effect of the preform cavity in two stage superplastic forming
المؤلف الرئيسي:	Jafar, Reem Ahmad Mousa
مؤلفين آخرين:	Al Huniti, Naser Shafei Naji(sup)
التاريخ الميلادي:	2014
موقع:	عمان
الصفحات:	1 - 105
رقم MD:	718234
نوع المحتوى:	رسائل جامعية
اللغة:	English
الدرجة العلمية:	رسالة ماجستير
الجامعة:	الجامعة الاردنية
الكلية:	كلية الدراسات العليا
الدولة:	الاردن
قواعد المعلومات:	Dissertations
مواضيع:	الهندسة الميكانيكية، التشكيل الفائق الطواعية
رابط:	https://search.mandumah.com/Record/718234

USING FINITE ELEMENT SIMULATION TO PREDICT THE EFFECT OF THE PREFORM CAVITY IN TWO-STAGE SUPERPLASTIC FORMING

By
Reem Ahmad MousaJafar

Supervisor
Dr. Naser S. Al-Huniti, Prof.

ABSTRACT

Superplastic Forming (SPF) is a high temperature forming operation for producing complex thin components in a single manufacturing process. It relies on the fact that certain materials can undergo large ductility under certain conditions. These conditions are forming within a specific range of strain rates, and forming in narrow ranges of temperature. The SPF process has many unique advantages over conventional forming operations including significant cost and weight savings potentials. However, the conventional SPF can result in excessive thinning at certain locations and produce a non-uniform thickness profile of the final formed part. To address these issues, a two-stage SPF process has been developed to improve the uniformity of thickness distribution. The two-stage SPF process is carried out by stretching the superplastic sheet at certain locations, while preserving material thickness in the regions experienced thinning in the conventional one-stage SPF, before the forward forming stage.

In this work, two techniques are applied to improve the final thickness distribution of a complex and practical shape, namely, the license plate pocket potion of the Oldsmobile Aurora decklid outer panel. These two techniques are the reverse free bulging and sheet preforming. The commercial finite element code, ABAQUS™, has been used to model the two-stage SPF process of an aluminum alloy AA5083 sheet at 450 °C. Finally, an engineered preform cavity has been designed to improve the thickness profile of the formed part.

It is found that the reverse free bulging technique did not result in the desired improvement in the thickness distribution of the final part. On the other hand, the two-stage SPF with sheet preforming has improved the thickness profile obtained from the one-stage SPF.

استخدام محاكاة العنصر المحدود للتنبؤ بتأثير تجويف ما قبل التشكيل في التشكيل الفائق الطواعية ذو المرحلتين

إعداد
ريم أحمد موسى جعفر

المشرف
الأستاذ الدكتور ناصر الحنيطي

ملخص

التشكيل الفائق الطواعية هي عملية تشكيل عند درجة حرارة عالية لانتاج عناصر رقيقة معقدة في عملية تصنيع واحدة. تعتمد على حقيقة أن بعض المواد يمكن أن تخضع لليونة كبيرة في ظل ظروف معينة. هذه الظروف هي التشكيل ضمن نطاق محدد من معدلات الاجهاد، و التشكيل في نطاقات ضيقة لدرجة الحرارة. عملية التشكيل الفائق الطواعية لها العديد من المزايا الفريدة التي تميزها عن عمليات التشكيل التقليدية منها امكانيات كبيرة في توفير التكاليف و الوزن. لكن التشكيل الفائق الطواعية التقليدي يمكن أن يؤدي الى ترققات مفرطة في بعض المواقع و ينتج توزيع غير منتظم لسماكة الجزء النهائي المشكل. لمعالجة هذه القضايا، تم تطوير عملية تشكيل فائق الطواعية ذات مرحلتين لتحسين انتظام توزيع السمك. يتم تنفيذ العملية من خلال تمديد الصفيحة الفائقة الطواعية في مواقع معينة، مع الحفاظ على سمك المادة في المناطق التي شهدت ترقق في عملية التشكيل الفائق الطواعية التقليدية ذات المرحلة الواحدة، قبل مرحلة التشكيل الأمامية.

في هذا العمل، يتم تطبيق تقنيتين لتحسين توزيع السمك النهائي لشكل معقد و عملي، و هو، الجزء الخارجي من جيب لوحة رخصة سيارة. هاتان التقنيتان هما الانتفاخ الحر العكسي و التشكيل المسبق للصفيحة. البرنامج التجاري للعنصر المحدود، ABAQUS^{TM} ، استخدم لتمثيل عملية التشكيل الفائق الطواعية ذات المرحلتين لصفيحة سبيكة الألمنيوم AA5083 عند درجة حرارة ٤٥٠ درجة مئوية. في النهاية، تم تصميم تجويف ما قبل التشكيل لتحسين توزيع سماكة الجزء الذي تم تشكيله.

وجد أن تقنية الانتفاخ الحر العكسي لم تؤدي الى التحسن المطلوب في توزيع سمك الجزء الأخير. من ناحية أخرى، التشكيل الفائق الطواعية ذو المرحلتين مع التشكيل المسبق للصفيحة حسن توزيع السمك الذي تم الحصول عليه من التشكيل الفائق الطواعية ذو المرحلة الواحدة.

العنوان:	Using finite element simulation to predict the effect of the preform cavity in two stage superplastic forming
المؤلف الرئيسي:	Jafar, Reem Ahmad Mousa
مؤلفين آخرين:	Al Huniti, Naser Shafei Naji(sup)
التاريخ الميلادي:	2014
موقع:	عمان
الصفحات:	1 - 105
رقم MD:	718234
نوع المحتوى:	رسائل جامعية
اللغة:	English
الدرجة العلمية:	رسالة ماجستير
الجامعة:	الجامعة الاردنية
الكلية:	كلية الدراسات العليا
الدولة:	الاردن
قواعد المعلومات:	Dissertations
مواضيع:	الهندسة الميكانيكية، التشكيل الفائق الطواعية
رابط:	https://search.mandumah.com/Record/718234

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

SPF	Superplastic Forming
JIS	Japanese Industrial Standards
FEA	Finite element analysis
FE	Finite element
AA5083	Aluminum alloy 5083
MRI	Magnet resonance imaging
SMT	Siemens magnet technology
2D	Two-dimensional
3D	Three-dimensional
GM	General Motors
CPU	Central processing unit
σ	Effective flow stress (MPa)
ε	Effective strain
$\dot{\varepsilon}$	Effective strain rate (1/sec)
k	Strength coefficient
m	Strain rate sensitivity exponent
n	Strain hardening exponent
α_i	Material parameters
ρ	Radius of curvature (mm)
a	Radius of the die (mm)
S	Thickness after some time (mm)
S_0	Original sheet thickness (mm)
t	Time (seconds)
P	Applied pressure (MPa)
h	Dome height (mm)
$\dot{\bar{\varepsilon}}^{cr}$	Uniaxial equivalent creep strain rate (1/sec)
$\tilde{q}$	Uniaxial equivalent deviatoric stress (MPa)
$\bar{\varepsilon}^{cr}$	Equivalent creep strain
A, $\bar{m}$ and $\bar{n}$	Material parameters
$\dot{\bar{\varepsilon}}_{max}$	Maximum equivalent creep strain rate (1/sec)
$\dot{\bar{\varepsilon}}_{tar}$	Target creep strain rate (1/sec)
r	Strain rate ratio
P_{new}	New pressure magnitude (MPa)
P_{old}	Old pressure magnitude (MPa)
U2	Displacement in Y-direction (mm)
$L_{preform}$	Preform length of line (mm)
L_{part}	Part length of line (mm)

العنوان:	Using finite element simulation to predict the effect of the preform cavity in two stage superplastic forming
المؤلف الرئيسي:	Jafar, Reem Ahmad Mousa
مؤلفين آخرين:	Al Huniti, Naser Shafei Naji(sup)
التاريخ الميلادي:	2014
موقع:	عمان
الصفحات:	1 - 105
رقم MD:	718234
نوع المحتوى:	رسائل جامعية
اللغة:	English
الدرجة العلمية:	رسالة ماجستير
الجامعة:	الجامعة الاردنية
الكلية:	كلية الدراسات العليا
الدولة:	الاردن
قواعد المعلومات:	Dissertations
مواضيع:	الهندسة الميكانيكية، التشكيل الفائق الطواعية
رابط:	https://search.mandumah.com/Record/718234

USING FINITE ELEMENT SIMULATION TO PREDICT THE EFFECT OF THE PREFORM CAVITY IN TWO-STAGE SUPERPLASTIC FORMING

By

Reem Ahmad Mousa Jafar

Supervisor

Dr. Naser S. Al-Huniti, Prof.

This Thesis was Submitted in Partial Fulfillment of the Requirements for the Master's Degree of Science in Mechanical Engineering

Faculty of Graduate Studies

The University of Jordan

May, 2014

نموذج ترخيص

أنا الطالبة: ريم أحمد موسى جعفر أمنح الجامعة الأردنية و/ أو من تفوضه ترخيصاً غير حصري دون مقابل بنشر و / أو استعمال و / أو استغلال و / أو ترجمة و / أو تصوير و / أو إعادة إنتاج بأي طريقة كانت سواء ورقية و / أو إلكترونية أو غير ذلك رسالة الماجستير / الدكتوراه المقدمة من قبلي وعنوانها.

Using Finite Element Simulation to Predict the Effect of the Preform Cavity on Two-Stage Superplastic Forming.

وذلك لغايات البحث العلمي و / أو التبادل مع المؤسسات التعليمية والجامعات و / أو لأي غاية أخرى تراها الجامعة الأردنية مناسبة، وأمنح الجامعة الحق بالترخيص للغير بجميع أو بعض ما رخصته لها.

اسم الطالب: ريم أحمد موسى جعفر

التوقيع: Reem Jafar

التاريخ: ٢٠/٥/٢٠١٤

COMMITTEE DECISION

This Thesis (Using Finite Element Simulation to Predict the Effect of the Preform Cavity in Two-Stage Superplastic Forming) was Successfully Defended and Approved on May 14, 2014

Examination Committee	**Signature**
Dr. Naser Al-Huniti (Supervisor) Prof. of Applied Mechanics	Naser Al-Huniti
Dr. Osama Abu Zeid (Member) Prof. of Applied Mechanics	
Dr. Moudar Zgoul (Member) Assoc. Prof. of Applied Mechanics	
Dr. Saad Al-Hubaili (Member/ External Examiner) Prof. of Applied Mechanics (Retired)	

تعتمد كلية الدراسات العليا
هذه النسخة من الرسالة
التوقيع.....التاريخ.....

DEDICATION

Dedicated To My Parents, Husband and Sisters

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisor Prof. Naser Al-Huniti for his support, patience, and motivation. His guidance helped me in all the time of research and writing this thesis.

I amalso deeply thankful to Dr. FirasJarrar for his continuous support. I was motivated by his knowledge in superplastic forming. Thank you for believing in my abilities and helping me in all stages of this thesis.

Last but not least, I would like to thank my parents, husband and sisters for always believing in me, for their continuous love and their support. This thesis would not have been possible without your help.

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

SPF	Superplastic Forming
JIS	Japanese Industrial Standards
FEA	Finite element analysis
FE	Finite element
AA5083	Aluminum alloy 5083
MRI	Magnet resonance imaging
SMT	Siemens magnet technology
2D	Two-dimensional
3D	Three-dimensional
GM	General Motors
CPU	Central processing unit
σ	Effective flow stress (MPa)
ε	Effective strain
$\dot{\varepsilon}$	Effective strain rate (1/sec)
k	Strength coefficient
m	Strain rate sensitivity exponent
n	Strain hardening exponent
α_i	Material parameters
ρ	Radius of curvature (mm)
a	Radius of the die (mm)
S	Thickness after some time (mm)
S_0	Original sheet thickness (mm)
t	Time (seconds)
P	Applied pressure (MPa)
h	Dome height (mm)
$\dot{\bar{\varepsilon}}^{cr}$	Uniaxial equivalent creep strain rate (1/sec)
$\tilde{q}$	Uniaxial equivalent deviatoric stress (MPa)
$\bar{\varepsilon}^{cr}$	Equivalent creep strain
A, $\bar{m}$ and $\bar{n}$	Material parameters
$\dot{\bar{\varepsilon}}_{max}$	Maximum equivalent creep strain rate (1/sec)
$\dot{\bar{\varepsilon}}_{tar}$	Target creep strain rate (1/sec)
r	Strain rate ratio
P_{new}	New pressure magnitude (MPa)
P_{old}	Old pressure magnitude (MPa)
U2	Displacement in Y-direction (mm)
$L_{preform}$	Preform length of line (mm)
L_{part}	Part length of line (mm)

USING FINITE ELEMENT SIMULATION TO PREDICT THE EFFECT OF THE PREFORM CAVITY IN TWO-STAGE SUPERPLASTIC FORMING

By
Reem Ahmad MousaJafar

Supervisor
Dr. Naser S. Al-Huniti, Prof.

ABSTRACT

Superplastic Forming (SPF) is a high temperature forming operation for producing complex thin components in a single manufacturing process. It relies on the fact that certain materials can undergo large ductility under certain conditions. These conditions are forming within a specific range of strain rates, and forming in narrow ranges of temperature. The SPF process has many unique advantages over conventional forming operations including significant cost and weight savings potentials. However, the conventional SPF can result in excessive thinning at certain locations and produce a non-uniform thickness profile of the final formed part. To address these issues, a two-stage SPF process has been developed to improve the uniformity of thickness distribution. The two-stage SPF process is carried out by stretching the superplastic sheet at certain locations, while preserving material thickness in the regions experienced thinning in the conventional one-stage SPF, before the forward forming stage.

In this work, two techniques are applied to improve the final thickness distribution of a complex and practical shape, namely, the license plate pocket potion of the Oldsmobile Aurora decklid outer panel. These two techniques are the reverse free bulging and sheet preforming. The commercial finite element code, ABAQUS™, has been used to model the two-stage SPF process of an aluminum alloy AA5083 sheet at 450 °C. Finally, an engineered preform cavity has been designed to improve the thickness profile of the formed part.

It is found that the reverse free bulging technique did not result in the desired improvement in the thickness distribution of the final part. On the other hand, the two-stage SPF with sheet preforming has improved the thickness profile obtained from the one-stage SPF.

CHAPTER 1

INTRODUCTION

Superplastic forming (SPF) is a high temperature forming operation for producing complex thin sheet components in a single manufacturing process. It relies on the fact that some materials can undergo large ductility under certain conditions.

The SPF has many unique advantages over conventional forming processes including greater design flexibility, forming light weight components with complex geometries in one manufacturing step, low dies cost and the elimination of spring back. Although SPF offers many advantages it still faces many problems that hamper its widespread use. These limitations include the non-uniformity of the produced part thickness, long forming times, the possibility of severe thinning and necking at certain locations and large amounts of cavities developed in some superplastic alloys.

Two-stage SPF is a process that utilizes two stages of gas forming within one die. During the first stage, the superplastic material sheet is forced to take the shape of the preform cavity. This preform cavity is designed in a way to pre-stretch the sheet and increase the thickness at the critical locations which experienced thinning in the conventional SPF. Currently, the two-stage SPF process is mainly based on finite element analysis (FEA) and experimental iterations.

In order for the two-stage SPF process to become an efficient forming operation, its output should be predictable and the forming time must be reduced without compromising the integrity of the produced parts. In addition, the thickness distribution of the formed

parts must be improved, even though a certain amount of deviation cannot be avoided due to the stretching of the sheet. All of this requires developing accurate material models and the execution of thorough experimental and numerical investigations.

1.1 Background

1.1.1 Superplasticity

Superplasticity is the ability of certain type of materials to exhibit large tensile deformation prior to fracture. The conditions for superplasticity to occur are forming within a specific range of strain rates, and forming in narrow ranges of temperatures. Each material has a unique optimum value of strain rate, and a narrow temperature range which lies above half the material's absolute melting point (Lin, 2003). Figure 1.1 shows a comparison between conventional and superplastic tensile testing of an Aluminum specimen (Yarlagadda, et al., 2002).

Figure 1.1 Comparison of conventional and superplastic tensile testing (Yarlagadda, et al., 2002).

1.1.2 History of Superplasticity

The history of superplasticity can be divided into three main time periods: before 1962, from 1962 to 1982, and from 1982 to the present.

1.1.2.1 Before 1962

According to Nieh, et al. (1997) this stage began with a paper published by Bengoughin 1912 which is believed to contain the first recorded description of superplasticity in a metallic material. In 1934, Pearson observed the unusual large elongations that could be achieved in certain fine-structured materials. Later on, in 1945, Bochvar and Sviderskajo put the expression Superplastichnost (ultrahigh plasticity) in their paper on superplastic alloys. The term Superplasticity first appeared in a technical paper by Lozinsky and Simeonovain 1959. Figure 1.2 summarizes the key observations and discoveries in superplasticity through this stage (Nieh, et al., 1997).

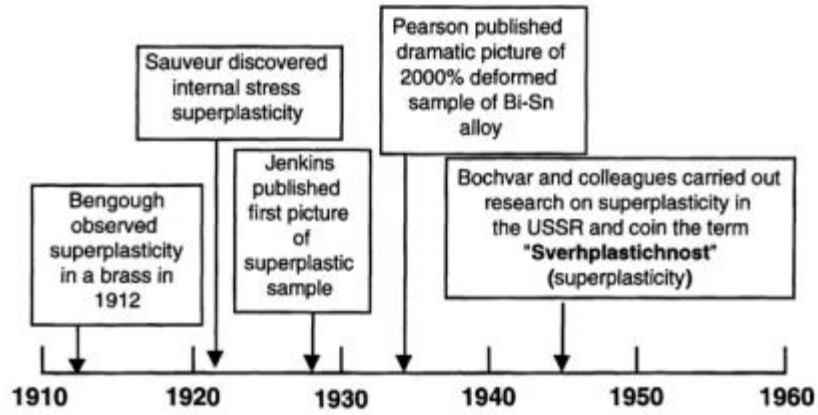

Figure 1.2 Key discoveries in superplasticity in the early and middle part of the twentieth century (Nieh, et al., 1997).

1.1.2.2 From 1962 to 1982

The major increase in interest in superplasticity came in 1964, when Backofen, et al. published a paper suggesting applying polymer and glass forming techniques in superplastic metals forming. By 1969, the first book entitled*Superplasticity of Metals and Alloys* was published by Presnyakov. After that, numerous papers on superplasticity were

issued. Following these publications, SPF became a process for manufacturing lightweight complex components in many applications.

1.1.2.3 From 1982 to the Present

During this time period, many conferences were held on SPF, and numerous papers were published to eliminate the limitations of SPF that hamper its widespread use. In the present stage, the focus is pointed towards making SPF the manufacturing choice for lightweight complex components in high rate mass production.

1.1.3 Superplastic Materials

Superplastic materials are polycrystalline solids which, under certain conditions, have the capability to exhibit very large elongations, i.e. >500%. While the maximum elongation prior to failure that can be achieved in conventional alloys does not exceed 120%, regardless of the pulling speed or temperature (Pilling and Ridley, 1989). However, large elongations usually occur in a low strain rate range from 10^{-5} to 10^{-3} s^{-1}. Superplasticity which occur at strain rates $>10^{-2}$ s^{-1} is defined as high strain rate superplasticity in Japanese Industrial Standards (JIS) H 7007 by Japanese Standards Association. Aluminum- and titanium-based materials are high strain rate superplastic materials (Yarlagadda, et al., 2002).

Superplasticity has been noticed in various types of materials, such as ceramics (including composites and monoliths), metals (including aluminum, iron, magnesium, titanium and nickel-based alloys), intermetallics (including iron, nickel, and titanium base)

and laminates (Xing, et al., 2004). The main metallurgical requirements for these materials to exhibit superplasticity are fine equi-axed grain structure, grain size in the range of 2 to 10 micrometers (Pilling and Ridley, 1989), and a resistance to both grain growth and cavities formation (Siegert and Werle, 1994).

1.1.3.1 Aluminum Alloys

Aluminum alloys have been used to produce superplastically formed parts for the automotive, aerospace, marine, and architectural industries (Osada, 1997, Nakamura, et al. 1997 and Barnes, 1999). These alloys can be used where low weight and high stiffness are required (Xing, et al., 2004). The main characteristics of Aluminum alloys are: low weight, good corrosion resistance, and relatively moderate strength (Verma, et al., 1996). Superplastically formed Aluminum alloys have the ability to be stretched to several times their original size without failure when heated to between 470 – 520 °C (Mikhailovskaya, et al., 2012).

1.1.3.2 Magnesium Alloys

Magnesium has been receiving a great attention over the last decade since it is the lightest constructional metal on earth (Nazzal, et al., 2011, a). Magnesium alloys are attractive for applications where light weight and rigidity are the key elements for component design. The lower density of Magnesium over currently used aerospace Aluminum alloys have been the dominant driving force for using Magnesium alloys. However, these alloys have relatively low strength which restricts their usage to

applications where high strength is not necessarily needed (Park, et al., 1996 and Carrino, et al., 2013).

1.1.3.3 Titanium Alloys

Titanium alloys have been used in aerospace and automobile industries. The main characteristics of these alloys are: low weight-size ratio, high relative strength, resistance to corrosion, high temperature creep resistance, and they do not need post-forming heat treatment (Sieniawski and Motyka, 2007 and Yarlagadda, et al., 2002). Titanium alloy Ti-6Al-4V has both excellent biocompatibility and superior mechanical properties. It can be deformed greatly and easily at the superplastic temperature range of 800 - 900 °C (Okuno, et al., 1989).

1.1.4 Material Behavior

Materials undergoing the superplastic forming operation have common characteristics including a fine and stable grain size, and a low flow stress. The flow stress in these materials is highly sensitive to the strain rate. A simple form of the constitutive equation that describes this strain rate dependence for superplastic materials is given by (Avery and Backofen, 1965):

$$\sigma = k\dot{\varepsilon}^m \tag{1.1}$$

Where σ is the effective flow stress,$\dot{\varepsilon}$ is the effective strain rate, k is the strength coefficient, and m is the strain rate sensitivity exponent, which should be greater than 0.3

for superplastic behavior to exist (Pilling and Ridley, 1989). The strain rate sensitivity exponent or the m-value, which ranges from 0.3 to 0.8 for superplastic materials, is a measure of a material's ability to resist necking. Higher values of $m$gives higher tensile elongation behavior for superplastic materials (Avery and Backofen, 1965).

The function of strain rate sensitivity in necking resistance can be explained by considering tensile testing of a specimen under a constant strain rate condition. When a neck begins to develop, the strain rate locally increases in the necked region and becomes larger than the strain rate in the rest of the tensile specimen. According to equation (1.1) and because of the high value of m, the desired flow stress would increase sharply in response to the increase in the strain rate in the necked region in order to continue deformation in that region. This would cause the material flow to occur outside the necked region. Thus, strain rate hardening in that region prevents additional necking development (Pilling and Ridley, 1989 and Siegert and Werle, 1994). As a result, a high m-value gives a high resistance to neck development and leads to high tensile elongations prior to failure characteristic of superplastic materials (Hedworth and Stowel, 1971).

A typical stress/strain rate relation for superplastic materials is shown on logarithmic scales in figure 1.3. According to equation 1.1, the slope of the curve is equal to the strain rate sensitivity exponent; this can also be seen from the second part of figure 1.3, which shows the variation of the strain rate sensitivity exponent with strain rate. The sigmoidal shape in figure 1.3 can be divided into three regions based on the m-value. Note that regions I and III, which represent the low strain rate and high strain rate regions, respectively, have a strain rate sensitivity exponent value of less than 0.3. Thus, superplasticity is not observed when forming under the conditions of these two regions. On

the other hand, superplasticity occurs only in region II, which is the moderate strain rate region, where the strain rate sensitivity exponent has values greater than 0.3, accompanied by very large elongations. Unfortunately, this moderate strain rate region ranges between 10^{-5} – 10^{-2} 1/sec, which is considered very low for high production rates.

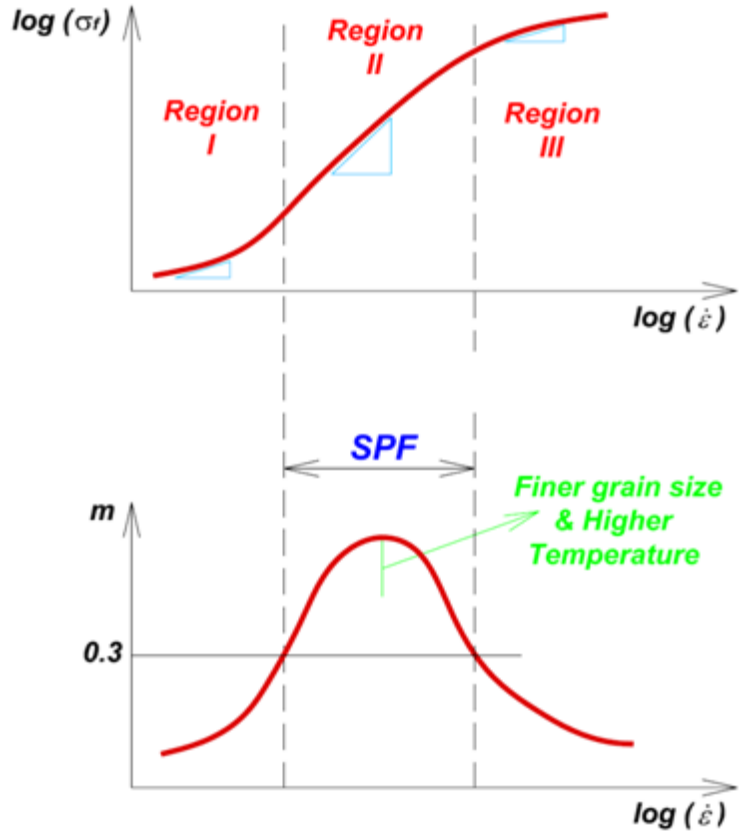

Figure 1.3 Stress-strain rate curve for typical superplastic materials and the corresponding strain rate sensitivity (Abu-Farha, 2007).

It should be noted here that the mechanical behavior of superplastic materials is very sensitive to both temperature and grain size. Generally, increasing the forming temperature or decreasing the grain size of the material increases both the strain rate sensitivity exponent and the strain rate, however the flow stresses decrease (Pilling and Ridley, 1989).

1.1.5 Superplastic Forming Technique

The SPF process is carried out by heating a sheet of superplastic material placed on a single-sided die. As mentioned previously, the sheet is heated to the required SPF temperature which is specified for that material. Then, an inert gas is applied to one side of the sheet to control the rate of deformation and force the sheet to take the shape of the die cavity. The SPF process is illustrated schematically in figure 1.4.

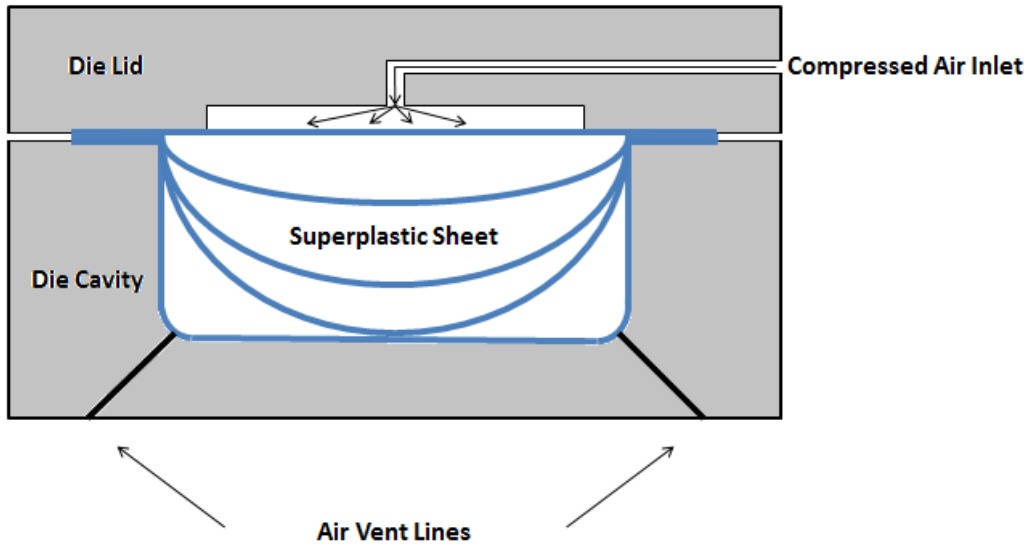

Figure 1.4 Schematic illustration of a single-stage SPF die (Luckey, et al., 2009).

There are two main types of SPF, cavity forming and bubble forming. Cavity forming is most commonly used and ideal for producing large complex parts such as car body panels, building cladding panels and large rail parts. This process is ideally suited to forming 5083 aluminum alloys and Magnesium. In cavity forming a sheet of superplastic material is heated and placed on a single-sided die. A pressurized gas is then applied to one side of the sheet forcing it to take the shape of the die cavity. The other type of SPF, which is referred to as bubble forming, is ideal for producing small components, where material

العنوان:	Using finite element simulation to predict the effect of the preform cavity in two stage superplastic forming
المؤلف الرئيسي:	Jafar, Reem Ahmad Mousa
مؤلفين آخرين:	Al Huniti, Naser Shafei Naji(sup)
التاريخ الميلادي:	2014
موقع:	عمان
الصفحات:	1 - 105
رقم MD:	718234
نوع المحتوى:	رسائل جامعية
اللغة:	English
الدرجة العلمية:	رسالة ماجستير
الجامعة:	الجامعة الاردنية
الكلية:	كلية الدراسات العليا
الدولة:	الاردن
قواعد المعلومات:	Dissertations
مواضيع:	الهندسة الميكانيكية، التشكيل الفائق الطواعية
رابط:	https://search.mandumah.com/Record/718234

USING FINITE ELEMENT SIMULATION TO PREDICT THE EFFECT OF THE PREFORM CAVITY IN TWO-STAGE SUPERPLASTIC FORMING

By

Reem Ahmad Mousa Jafar

Supervisor

Dr. Naser S. Al-Huniti, Prof.

This Thesis was Submitted in Partial Fulfillment of the Requirements for the Master's Degree of Science in Mechanical Engineering

Faculty of Graduate Studies

The University of Jordan

May, 2014