INVESTIGATIONS ON DEEP DRAWING OF HIGH STRENGTH STEEL SHEETS USING TEXTURED DIES

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INVESTIGATIONS ON DEEP DRAWING OF HIGH STRENGTH STEEL SHEETS USING TEXTURED DIES

by

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Submitted

In fulfillment of the requirements of the degree of Doctor of Philosophy

to the

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Dedicated to

My Parents

and

My wife and daughter

CERTIFICATE

This is to certify that the thesis entitled "Investigations on Deep Drawing of High Strength Steel Sheets using Textured Dies" being submitted by Mr. Archit Shrivastava to the Indian Institute of Technology Delhi for the award of the degree of Doctor of Philosophy in Department of Mechanical Engineering is a bonafide research work carried out by him under my supervision and guidance. To the best of my knowledge, the thesis has reached the requisite standard. The research reports and the results presented in this thesis have not been submitted in parts or in full to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

In sheet metal forming, surface texturing of dies is a potential method of modifying the die surface by creating dimples or microcavities on the surface. The surface texture can influence tribological performance resulting in significant changes in friction, formability, and forming load. In view of this, the present thesis deals with investigations on deep drawing of high strength steel (Dual Phase steel of grade DP600) sheets using laser textured dies.

The surface texture parameters such as dimple size, depth and area density affect friction, formability and forming load. Also, defining a constant friction coefficient based on the Coulomb's law is the most common practice in FE simulation of deep drawing. Therefore, it is necessary to incorporate the effect of process variables on the friction coefficient for more accurate prediction of drawability and drawing load. Using advanced friction models, the real time friction coefficient value can be incorporated in the simulation instead of assuming a constant friction coefficient value and it is particularly important for a textured die. Therefore, in this work, a setup for strip drawing experiments has been designed and developed to study of the effect of texture parameters on coefficient of friction in strip drawing of DP600 steel sheets using laser textured dies. The effect of process variables (normal load and sliding velocity) on the coefficient of friction in strip drawing using the textured dies has been studied and a regression model has been developed to predict the coefficient of friction. Using the experimental data, the coefficients in a pressure and velocity dependent friction model have been determined.

FE simulation of deep drawing of DP600 steel sheets has been carried out incorporating variation of friction coefficient with contact pressure and sliding velocity through the pressure and velocity dependent friction model. In the material model, Swift hardening law has been used to plot the flow curve using the coefficients determined from uniaxial tensile tests and hydraulic bulge tests. The yield surface, defined using the BBC2005 yield model, has been used to incorporate the effect of anisotropy. To determine the coefficients in the yield criterion, the required stress ratios and plastic strain ratios were experimentally determined from uniaxial tensile tests and the biaxial properties were determined by cruciform biaxial tensile tests.

To validate the predicted drawability, drawing load, and thickness variations, textured dies for deep drawing have been designed and developed using laser surface texturing with the

optimum texture parameters identified using the strip drawing experiments earlier. Two deep drawing dies, one with texture only in the flange region (TF) and the other with texture in both the flange and the die corner regions (TFC), have been used in the experiments.

The textured die showed better tribological properties resulting in lower friction coefficient in strip drawing of DP600 sheet than an untextured surface in conditions similar to that exist in flange area in a deep drawing process. The microcavities on the textured surface help in storage, transportation and distribution of lubricant and wear particles, leading to a more stable friction coefficient. The combination of 125 µm cavity diameter and 10% texture area density has resulted in the minimum friction coefficient. The effect of process parameters (normal pressure and sliding speed) has been found to be more significant with textured dies than with untextured die in strip drawing.

In deep drawing of cylindrical cups, the textured die with texture in both flange and die corner regions resulted in about 10% improvement in the maximum draw depth and a reduction of 8% in the peak drawing load as compared to the untextured die. Texture present in the die corner radius provides effective lubrication which leads to a decrease in friction by maintaining a lubricant film between the contacting surfaces. It helps smooth flow of metal into the die cavity reducing the load required to draw the blank. A maximum thinning of 21.5% has been observed for the untextured die and the textured dies showed a significant reduction in the maximum thinning which is 20.4% and 17.5% for TF die and TFC die, respectively. In the case of TFC die, a more uniform reduction in friction leads to more uniformity in strain distribution leading lower thinning in the punch corner region.

The simulation of deep drawing with PVDF friction model incorporates the variation of friction coefficient with speed and contact pressure. The error in the prediction of maximum load is 11% using a constant friction coefficient and it decreased to 3% when the PVDF model is used. When compared to the initial blank, a large reduction (52.6%) in the average roughness value (Ra) has been observed in the wall region of the cup drawn using the textured die with a lower viscosity lubricant and a reduction of 32.9% has been observed with a higher viscosity lubricant.
Keywords: Deep drawing, Laser textured dies, Friction, Lubrication, Dual phase steel, FE simulation

सार

शीट मेटल फॉर्मिंग में, डाई की सतह को टेक्सचर करना डाई की सतह को डिम्पल्स या माइक्रोकेविटीज़ बनाने का एक संभावित तरीका है। सतह की टेक्सचर घर्षण, फॉर्मेबिलिटी, और फॉर्मिंग लोड में महत्वपूर्ण परिवर्तनों के कारण ट्राइबोलॉजिकल प्रदर्शन को प्रभावित कर सकती है। इस संदर्भ में, वर्तमान थीसिस उच्च शक्ति वाले इस्पात की (ग्रेड DP600) शीटों की गहरी खींचाई पर जाँच करती है, जिसमें लेजर टेक्सचरड डाई का उपयोग किया गया है।

डिम्पल आकार, गहराई और क्षेत्र घनत्व जैसे सतह टेक्सचर पैरामीटर घर्षण, फॉर्मेबिलिटी और फॉर्मिंग लोड पर प्रभाव डालते हैं। इसके अलावा, कूलंब कानून के आधार पर एक स्थिर घर्षण संघ संघ की परिभाषा करना डीप ड्राइंग के एफई सिमुलेशन में सबसे सामान्य प्रथा है। इसलिए, खींचने की क्षमता और ड्राइंग लोड के अधिक सटीक पूर्वानुमान के लिए प्रक्रिया परिवर्तनों के प्रभाव को फ्रिक्शन संघ पर शामिल करना आवश्यक है। उन्नत फ्रिक्शन मॉडलों का उपयोग करके, वास्तविक समय में फ्रिक्शन संघ मूल्य को निश्चित फ्रिक्शन संघ मूल्य की तुलना में उपयोग किया जा सकता है और यह एक टेक्सचर्ड डाई के लिए विशेष रूप से महत्वपूर्ण है। इसलिए, इस काम में, डीपी600 इस्पात शीटों की स्ट्रिप ड्राइंग में टेक्सचर पैरामीटर के प्रभाव का अध्ययन करने के लिए एक सेटअप डिज़ाइन और विकसित किया गया है, जिसमें लेजर सर्फेस टेक्सचरिंग का उपयोग किया गया है। प्रक्रिया चरणों (सामान्य लोड और स्लाइडिंग वेलोसिटी) के प्रभाव पर टेक्सचर्ड डाई का उपयोग करके स्ट्रिप ड्राइंग में फ्रिक्शन संघ का प्रभाव अध्ययन किया गया है और फ्रिक्शन संघ का पूर्वानुमान करने के लिए एक रीग्रेशन मॉडल विकसित किया गया है। इसलिए, इस काम में, DP600 स्टील शीटों की स्ट्रिप ड्राइंग में टेक्सचर पैरामीटरों के प्रभाव का अध्ययन करने के लिए एक सेटअप स्ट्रिप ड्राइंग प्रयोगों के लिए डिज़ाइन और विकसित किया गया है, जिसमें लेजर सतह टेक्सचर्ड डाईज़ का उपयोग किया गया है। टेक्सचर्ड डाईज़ का उपयोग करने वाली स्ट्रिप ड्राइंग में घर्षण संघ के प्रति प्रक्रिया परिवर्तन (सामान्य लोड और स्लाइडिंग वेलोसिटी) का प्रभाव अध्ययन किया गया है और फ्रिक्शन संघ को पूर्वानुमान करने के लिए एक प्रतिकूल मॉडल विकसित किया गया है। प्रयोगात्मक डेटा का उपयोग करते हुए, दबाव और वेलोसिटी पर निर्भर फ्रिक्शन मॉडल में संख्याओं का निर्धारण किया गया है।

DP600 स्टील शीटों की डीप ड्राइंग के FE सिमुलेशन में फ्रिक्शन संघ के वार्तामान संपर्क दाब और स्लाइडिंग वेलोसिटी के साथ फ्रिक्शन संघ मॉडल के माध्यम से फ्रिक्शन संघ के विविधता को शामिल करके प्रक्रिया किया गया है। सामग्री मॉडल में, यूनिऐक्सियल टेंसाइल परीक्षण और हाइड्रोलिक बल्ज परीक्षण से निर्धारित संख्याओं का उपयोग करके फ्लो कर्व को प्लॉट करने के लिए स्विफ्ट हार्डेनिंग कानून का उपयोग किया गया है। BBC2005 यील्ड मॉडल का उपयोग करके पैरशानता के प्रभाव को शामिल करने के लिए यील्ड सरफेस का उपयोग किया गया है। यील्ड मानदंड में संख्याओं का निर्धारण करने के लिए, आवश्यक तनाव अनुपात और प्लास्टिक परिवाह अनुपातों का उपयोग यूनिऐक्सियल टेंसाइल परीक्षण से प्रयोगात्मक रूप से किया गया और द्विधारीय गुणों का निर्धारण क्रूसिफॉर्म द्विधारीय टेंसाइल परीक्षणों द्वारा किया गया है।

पूर्व में स्ट्रिप ड्राइंग प्रयोगों का उपयोग करके पहचाने गए आदर्श टेक्सचर पैरामीटर का उपयोग करके लेजर सतह टेक्सचर के साथ डीप ड्राइंग के लिए टेक्सचर्ड डाई डिज़ाइन और विकसित किए गए हैं, ताकि पूर्वानुमानित खींचने की क्षमता, ड्राइंग लोड, और मोटाई में परिवर्तनों की पुष्टि की जा सके।

प्रयोगों में दो डीप ड्राइंग डाईज़, एक में केवल फ्लैंज क्षेत्र में टेक्सचर (टीएफ) है और दूसरे में फ्लैंज और डाई कोनर क्षेत्रों दोनों में टेक्सचर है (टीएफसी), का उपयोग किया गया है।

टेक्सचर्ड डाई ने डीप ड्राइंग प्रक्रिया में फ्लैंज क्षेत्र में मौजूद वातावरण के समान शर्तों में DP600 शीट की स्ट्रिप ड्राइंग में एक अटेक्सचर्ड सतह से कम घर्षण संघ का उत्तम संपत्तियों का प्रदर्शन किया। टेक्सचर्ड सतह पर माइक्रोकेविटीज़ तेल और गिरा अणुओं को भंडारण, परिवहन और वितरण में मदद करते हैं, जिससे एक स्थिर घर्षण संघ मान प्राप्त होता है। 125 μm गड्ढे के व्यास और 10% टेक्सचर क्षेत्र घनत्व का संयोजन न्यूनतम घर्षण संघ मान के प्राप्त होने का कारण बना है। प्रक्रिया पैरामीटरों (सामान्य दबाव और स्लाइडिंग गति) का प्रभाव, टेक्सचर्ड डाईज़ के साथ अटेक्सचर्ड डाई के मुकाबले स्ट्रिप ड्राइंग में अटेक्सचर्ड डाईज़ के साथ अधिक महत्वपूर्ण पाया गया है।

सिलिंड्रिकल कप की गहरी खींचाई में, टेक्सचर्ड डाई जिसमें फ्लैंज और डाई कॉर्नर क्षेत्रों में टेक्सचर होने के कारण अपयास से कुल मान संख्या में लगभग 10% का सुधार और अपेक्षित डाई के समानता में पीक खींचने के भार में 8% की कमी हो गई। डाई कॉर्नर रेडियस में मौजूद टेक्सचर को प्रभावी लुब्रिकेशन प्रदान करता है जो संपर्क करने वाली सतहों के बीच लुब्रिकेशन फिल्म को बनाए रखकर घर्षण में कमी करता है। यह धातु का स्मूद धारण डाई केवल की लोड को कम करके डाई के गहराई में मेटल के स्मूद धारण में मदद करता है। अपेक्षित डाई के लिए अधिकतम पतलापन का लघुतमीकरण 21.5% के लिए देखा गया है और टेक्सचर्ड डाई ने अधिकतम पतलापन में काफी कमी दिखाई है जो कि टीएफ डाई और टीएफसी डाई के लिए लगभग 20.4% और 17.5% है। टीएफसी डाई के मामले में, घर्षण में अधिक समान कमी से पंच कॉर्नर क्षेत्र में पतलापन में और अधिक समानता है।

डीप ड्राइंग का पीवीडीएफ फ्रिक्शन मॉडल के साथ सिमुलेशन घास के घर्षण संघ के परिवर्तन को शामिल करता है जो गति और संपर्क दबाव के साथ फ्रिक्शन संघ की विविधता को शामिल करता है। स्थिर फ्रिक्शन संघ मान का पूर्वानुमान में 11% की गलती होती है जब एक स्थिर फ्रिक्शन संघ मान का उपयोग किया जाता है और यह 3% तक कम होता है जब पीवीडीएफ मॉडल का उपयोग किया जाता है। पहले रखरखाव के तुलना में, टेक्सचर्ड डाई का उपयोग करके कप के दीवार क्षेत्र में औसत असमर्थता मूल्य (आरए) में एक बड़ी कमी (52.6%) देखी गई है और एक निचले विस्कॉसिटी लुब्रिकेंट के साथ 32.9% की कमी देखी गई है।

शब्दकोष: डीप ड्राइंग, लेज़र टेक्सचर्ड डाईज़, घर्षण, लुब्रिकेशन, दोहरे चरणीय इस्पात, एफई सिमुलेशन

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ABBREVIATIONS

ANOVA	Analysis of Variance
BCC	Body-Centered Cubic
BEM	Bending Enhanced Membrane
BHF	Blank Holder Force
CT	Cruciform Test
DIC	Digital Image Correlation
DP	Dual-Phase
EBM	Electron Beam Machining
EBSD	Electron Backscatter Diffraction
ECM	Electro Chemical Machining
EDM	Electric Discharge Machining
FE	Finite Element
FLC	Forming Limit Curve
FLD	Forming Limit Diagram
GPA	Grid Pattern Analyser
HBT	Hydraulic Bulge Tests
HMI	Human Machine Interface
HRC	Rockwell C Scale
LDR	Limiting Draw Ratio
LST	Laser Surface Texturing
LVDT	Linear Variable Differential Transformer
PLC	Programable Logic Controller

PVDF	Pressure Velocity Dependent Friction
RD	Rolling Direction
SEM	Scanning Electron Microscope
TD	Transverse Direction
TF	Texture in the Flange
TFC	Texture in the Flange and the Die Corner
UAT	Uniaxial Tensile Test
UT	Untextured Die
UTS	Ultimate Tensile Strength
YS	Yield Strength