

**NUMERICAL AND EXPERIMENTAL INVESTIGATIONS ON
FORMABILITY FOR LIGHTWEIGHTING OF AN AUTOMOTIVE
FUEL TANK**

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FORMABILITY FOR LIGHTWEIGHTING OF AN AUTOMOTIVE
FUEL TANK**

**by
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Submitted

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Dedicated to

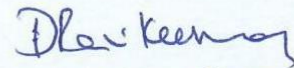
My Parents, grandparents

and

My wife

CERTIFICATE

This is to certify that the thesis entitled “**Numerical and Experimental Investigations on Formability for Lightweighting of an Automotive Fuel Tank**” being submitted by **Mr. Ravinder Kumar** to the Indian Institute of Technology Delhi for the award of the degree of Doctor of Philosophy in Department of Mechanical Engineering is a bonafied 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 this highly competitive environment, one of the most important tasks for all the automotive companies is to manufacture lightweight products to reduce the overall weight and the cost. This also results in increased fuel economy and reduced emissions. The body panels and other sheet metal parts constitute about 30-40% of the total weight of an automobile in the case of a four-wheeler and 30-35% in the case of a two-wheeler. Different sheet metal forming processes such as deep drawing, stretching, and bending are extensively used for manufacturing body panels and many other critical sheet metal parts for automobile applications. Some of the common examples are fuel tank, oil sump, B-pillar, front and rear fenders, etc. The success of sheet metal forming or stamping process of a complex automobile part depends on the ability of the sheet metal to undergo the required deformation, referred to as formability, without excessive thinning, necking, wrinkling, or fracture under the imposed forming conditions.

Different strategies for lightweight construction of a two-wheeler are proposed in the present thesis by exploring different methods to reduce the weight of critical sheet metal parts such as the fuel tank. A fuel tank is one of the most critical parts of an automobile because it contains gasoline which is a highly volatile liquid. Manufacturing a fuel tank is a critical process because it involves large plastic deformation of the sheet metal during forming. In view of this, in the present work, a two-wheeler fuel tank has been selected for formability investigations to explore the feasibility of manufacturing the fuel tank successfully with reduced weight. To achieve this, **three different strategies have been explored**, namely, reducing thickness and/or changing the steel grade, manufacturing the fuel tank with lightweight Al alloys, and using hydroforming technology to manufacture the fuel tank.

In the first part of this work, formability of a two-wheeler fuel tank has been investigated to explore the feasibility of reducing thickness and/or changing the steel grade in order to reduce the weight and improve fuel efficiency. Formability analysis has been carried out using numerical simulations on 0.8 mm thick sheet of Extra Deep Drawing (EDD) steel which is being used to manufacture the fuel tanks. Simulations were carried out using AutoForm software to find out the minimum initial sheet thickness which can be formed successfully without necking/failure. The effect of blank holding force and friction coefficient was also analyzed. Experiments were carried out to validate the predicted results such as strain distribution and thinning in the formed components. By reducing the thickness to the minimum

possible (0.70 mm), it has been found that the weight of the product can be reduced by nearly 12.5%. Simulations have also been carried out by changing the grade from EDD to Interstitial Free (IF) steel. Due to the superior drawability of IF steel, it has been found that thickness can be further reduced to 0.65 mm which is expected to result in 19% reduction in the weight of the component. Both the predictions have been validated by the actual press trials.

The future lightweight vehicle is likely to use a combination of available lightweight materials which have the potential to replace steel for various structural and other parts. An Al-intensive vehicle is one of the most potential ways to achieve vehicle weight reduction. In view of this, **in the second part of the work**, numerical simulations have been carried out to explore the feasibility of forming a two-wheeler fuel tank by using two different Al alloys, AA5052 and AA5754 (both 1 mm thick), commonly known for their ability to work harden and good properties. Due to their inferior formability when compared to EDD steel, successful forming could not be achieved. Experimental press trials also confirmed the predictions from the simulations. However, it was found that the fuel tank could be successfully formed in the case of AA5754 when the initial blank thickness is increased to 2 mm. Even with enhanced blank thickness, it would yield significant weight reduction in the case of this component.

Presently, the fuel tank of a two-wheeler is manufactured in two parts (upper left and upper right) which are welded after forming in a single die. Fuel tanks with large depth require multiple drawing steps. Apart from additional costs due to tooling, welding, and finishing operations, problems such as failure at joints and leakage are possible. These problems can be overcome by exploring innovative ways to manufacture a fuel tank. In view of this, the possibility of manufacturing a two-wheeler fuel tank with large depth as a single part by hydroforming technology has been explored using FE simulations in **the third part of this thesis**. The effect of peak pressure and clamping force on formability of 0.8mm thick EDD steels sheets has been studied in hydraulic bulging and the results obtained from simulations and lab scale experiments were in good agreement thus verifying the simulation methodology. Formability of the fuel tank with large depth has been studied in FE simulations by single stage and two stage hydroforming processes. It was found that a fuel tank with a large depth could be formed successfully as a single component by two-stage hydroforming with intermediate annealing thus eliminating the need for forming two separate parts followed by joining. It is expected to result in 42 % weight saving when compared to the conventional forming.

Keywords: Lightweighting, Formability, Deep drawing, Hydroforming, FE simulation

सार

इस अत्यधिक प्रतिस्पर्धी माहौल में, सभी ऑटोमोटिव कंपनियों के लिए सबसे महत्वपूर्ण कार्यों में से एक है कुल वजन और लागत को कम करने के लिए हल्के उत्पादों का निर्माण करना। इससे ईंधन की बचत भी बढ़ती है और उत्सर्जन भी कम होता है। चार पहिया वाहन के मामले में बॉडी पैनल और अन्य शीट धातु के हिस्से ऑटोमोबाइल के कुल वजन का लगभग 30-40% और दोपहिया वाहन के मामले में 30-35% होते हैं। ऑटोमोबाइल अनुप्रयोगों के लिए बॉडी पैनल और कई अन्य महत्वपूर्ण शीट मेटल भागों के निर्माण के लिए विभिन्न शीट मेटल बनाने की प्रक्रियाओं जैसे गहरी ड्राइंग, स्ट्रेचिंग और झुकने का बड़े पैमाने पर उपयोग किया जाता है। कुछ सामान्य उदाहरण ईंधन टैंक, तेल नाबदान, बी-स्तंभ, आगे और पीछे के फेंडर आदि हैं। एक जटिल ऑटोमोबाइल भाग की शीट मेटल बनाने या मुद्रांकन प्रक्रिया की सफलता शीट मेटल की आवश्यक विरूपण से गुजरने की क्षमता पर निर्भर करती है। जिसे फॉर्मैबिलिटी के रूप में संदर्भित किया जाता है, थोपी गई फॉर्मिंग स्थितियों के तहत अत्यधिक पतलापन, गर्दन सिकुड़ना, झुर्रियां या क्रैक्चर के बिना।

वर्तमान थीसिस में ईंधन टैंक जैसे महत्वपूर्ण शीट धातु भागों के वजन को कम करने के लिए विभिन्न तरीकों की खोज करके दोपहिया वाहन के हल्के निर्माण के लिए विभिन्न रणनीतियों का प्रस्ताव किया गया है। ईंधन टैंक ऑटोमोबाइल के सबसे महत्वपूर्ण हिस्सों में से एक है क्योंकि इसमें गैसोलीन होता है जो एक अत्यधिक अस्थिर तरल है। ईंधन टैंक का निर्माण एक महत्वपूर्ण प्रक्रिया है क्योंकि इसमें निर्माण के दौरान शीट धातु का बड़ा प्लास्टिक विरूपण शामिल होता है। इसे देखते हुए, वर्तमान कार्य में, कम वजन के साथ ईंधन टैंक के सफलतापूर्वक निर्माण की व्यवहार्यता का पता लगाने के लिए फॉर्मैबिलिटी जांच के लिए एक दोपहिया वाहन ईंधन टैंक का चयन किया गया है। इसे प्राप्त करने के लिए, तीन अलग-अलग रणनीतियों का पता लगाया गया है, अर्थात् मोटाई कम करना और/या स्टील ग्रेड बदलना, हल्के अल मिश्र धातुओं के साथ ईंधन टैंक का निर्माण करना, और ईंधन टैंक के निर्माण के लिए हाइड्रोफॉर्मिंग तकनीक का उपयोग करना।

इस कार्य के पहले भाग में, वजन कम करने और ईंधन दक्षता में सुधार करने के लिए मोटाई कम करने और/या स्टील ग्रेड को बदलने की व्यवहार्यता का पता लगाने के लिए दोपहिया वाहन ईंधन टैंक की संरचना की जांच की गई है। अतिरिक्त डीप ड्राइंग (ईडीडी) स्टील की 0.8 मिमी मोटी शीट पर संख्यात्मक सिमुलेशन का उपयोग करके फॉर्मैबिलिटी विश्लेषण किया गया है जिसका उपयोग ईंधन टैंक के निर्माण के लिए किया जा रहा है। न्यूनतम प्रारंभिक शीट मोटाई का पता लगाने के लिए ऑटोफॉर्म सॉफ्टवेयर का उपयोग करके सिमुलेशन किया गया था जिसे बिना नेकिंग/विफलता के सफलतापूर्वक बनाया जा सकता है। रिक्त धारण बल और घर्षण गुणांक के प्रभाव का भी विश्लेषण किया गया। गठित घटकों में तनाव वितरण और पतलेपन जैसे अनुमानित परिणामों को मान्य करने के लिए प्रयोग किए गए। मोटाई को

न्यूनतम संभव (0.70 मिमी) तक कम करके, यह पाया गया है कि उत्पाद का वजन लगभग 12% कम किया जा सकता है। ग्रेड को ईडीडी से इंटरस्टिशियल फ्री (आईएफ) स्टील में बदलकर सिमुलेशन भी किया गया है। आईएफ स्टील की बेहतर खींचने की क्षमता के कारण, यह पाया गया है कि मोटाई को 0.65 मिमी तक कम किया जा सकता है, जिसके परिणामस्वरूप घटक के वजन में 19% की कमी होने की उम्मीद है। दोनों भविष्यवाणियों को वास्तविक प्रेस परीक्षणों द्वारा मान्य किया गया है।

भविष्य के हल्के वाहन में उपलब्ध हल्के सामग्रियों के संयोजन का उपयोग करने की संभावना है जो विभिन्न संरचनात्मक और अन्य भागों के लिए स्टील को बदलने की क्षमता रखते हैं। वाहन के वजन में कमी लाने के लिए अल-सघन वाहन सबसे संभावित तरीकों में से एक है। इसे देखते हुए, कार्य के दूसरे भाग में, दो अलग-अलग अल मिश्र धातुओं, एए 5052 और एए 5754 (दोनों 1 मिमी मोटी) का उपयोग करके दोपहिया ईंधन टैंक बनाने की व्यवहार्यता का पता लगाने के लिए संख्यात्मक सिमुलेशन किया गया है। आमतौर पर कड़ी मेहनत करने की उनकी क्षमता और अच्छे गुणों के लिए जाना जाता है। ईडीडी स्टील की तुलना में उनकी निम्न फॉर्मैबिलिटी के कारण सफल फॉर्मेशन हासिल नहीं किया जा सका। प्रायोगिक प्रेस परीक्षणों ने भी सिमुलेशन से भविष्यवाणियों की पुष्टि की। हालाँकि, यह पाया गया कि AA 5754 के मामले में ईंधन टैंक सफलतापूर्वक बनाया जा सकता है जब प्रारंभिक रिक्त मोटाई 2 मिमी तक बढ़ जाती है। बड़ी हुई खाली मोटाई के साथ भी, इस घटक के मामले में वजन में महत्वपूर्ण कमी आएगी।

वर्तमान में, दोपहिया वाहन का ईंधन टैंक दो भागों (ऊपरी बाएँ और ऊपरी दाएँ) में निर्मित होता है, जिन्हें एक ही ड्राई में बनाने के बाद वेल्ड किया जाता है। बड़ी गहराई वाले ईंधन टैंकों को कई ड्राइंग चरणों की आवश्यकता होती है। टूलींग, वेल्डिंग और फिनिशिंग कार्यों के कारण अतिरिक्त लागत के अलावा, जोड़ों में विफलता और रिसाव जैसी समस्याएं संभव हैं। ईंधन टैंक के निर्माण के नवीन तरीकों की खोज करके इन समस्याओं को दूर किया जा सकता है। इसे देखते हुए, इस थीसिस के तीसरे भाग में एफई सिमुलेशन का उपयोग करके हाइड्रोफॉर्मिंग तकनीक द्वारा एकल भाग के रूप में दोपहिया ईंधन टैंक के निर्माण की संभावना का पता लगाया गया है। एकल चरण और दो चरण हाइड्रोफॉर्मिंग के एफई सिमुलेशन में प्रक्रिया मापदंडों (चरम दबाव, क्लैपिंग बल और घर्षण) और ड्राई डिज़ाइन के प्रभाव का अध्ययन किया गया है। हाइड्रोलिक बल्लिंग सिमुलेशन और लैब स्केल प्रयोगों से प्राप्त परिणाम अच्छे समझौते में थे, जिससे सिमुलेशन पद्धति की पुष्टि हुई। यह पाया गया कि 0.8 मिमी मोटी ईडीडी स्टील शीट का उपयोग करके दो-चरण हाइड्रोफॉर्मिंग द्वारा एक बड़ी गहराई वाले ईंधन टैंक को एक घटक के रूप में सफलतापूर्वक बनाया जा सकता है, जिससे जुड़ने के बाद दो अलग-अलग हिस्सों को बनाने की आवश्यकता समाप्त हो जाती है। इससे वजन और लागत दोनों में बचत होने की उम्मीद है।

कीवर्ड: फॉर्मैबिलिटी, डीप ड्राइंग, हाइड्रोफॉर्मिंग, प्यूल टैंक, एफई सिमुलेशन

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ABBREVIATIONS

ANOVA	Analysis of Variance
Barlat89	Barlat 1989
BCC	Body-centered cubic
BH	Bake hardened
BHF	Blank holding force
BIW	Body-in-white
BSE	Blank size engineering
CAD	Computer-aided design
CAE	Computer-aided manufacturing
CAM	Computer-aided engineering
CCT	Continuous cooling transformation
CFRP	Carbon fiber-reinforced plastics
CNC	Computer numeric control
CP	Complex phase
CP	Complex phase
DAS	Data acquisition system
DDQ	Deep draw quality
DDQ	diagonal direction
DP	Dual-phase
DQ	Draw quality
DSA	Dynamic strain aging
EDD	Extra-deep drawing
EDDQ	Extra deep draw quality
EPS	Elasto-plastic shell
FB	Ferritic Bainitic
FCC	Face-centered cubic
FE	Finite element
FEM	Finite element method
FLC	Forming limit curve
FLD	Forming limit diagram
GPA	Grid pattern analyzer

HBT	Hydraulic bulge test
HF	Hot formed
HSLA	High- strength low alloy
IE	Erichsen index
IF	Interstitial-free
IF-HS	Interstitial free high strength
LDH	Limiting dome height
LDR	Limiting draw ratio
MART	Martensitic
MIG	Metal inert gas
MP	Muli phase
PLC	Portevin–Le Chatelier
RD	Rolling direction
TD	Transverse direction
THR	Tailor heat-treated blank
TRB	Tailor Rolled Blank
TRIP	Transformation induced plasticity
TWB	Tailor welded blank
TWIP	Twinning Induced Plasticity
UTS	Ultimate tensile strength
YS	Yield strength