Faculty of Mechanical Engineering

CONCURRENT ENGINEERING APPROACH IN THE DEVELOPMENT OF NATURAL FIBRE METAL LAMINATE PRODUCT: CASE STUDY ON CAR FRONT HOOD

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A thesis submitted
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DECLARATION

I declare that this thesis entitled "Concurrent Engineering Approach in the Development of Natural Fibre Metal Laminate Product: Case Study on Car Front Hood" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……..

Name : Noordiana Binti Mohd Ishak

Date : ……..

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

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Date	:	……

DEDICATION

Specially dedicated to my beloved parent and siblings for their love, supports and prayers.

ABSTRACT

This thesis explores the solutions to improve fuel efficiency towards achieving the reduction in CO_2 emissions by utilizing the natural fibre metal laminate (nFML) as car front hood. Fibre metal laminate (FML) is a lightweight material that inherits advantages of metal and fibre reinforced composite which have outstanding physical and mechanical properties compared with monolithic metal structures. To date, very little research has been reported related to nFML. This research involved concurrent engineering approach in material selection for nFML car front hood using Fuzzy VIKOR method, generated inventive solutions through Theory of Inventive Problem Solving (TRIZ) method and investigated the formability and water absorption behaviour of the nFML to satisfy the intended product design specifications (PDS). Kenaf fibre and polypropylene have been identified as the suitable natural fibre and thermoplastic matrix for fabrication of the nFML using Fuzzy VIKOR method for the car front hood. Identification of problems or contradictions of nFML as car front hood system was constructed using TRIZ method; two layers of kenaf woven fibre [0º/90º] reinforced composite has been identified as the optimal stacking configuration for the reinforced composite in nFML. Forming analysis was conducted to determine the maximum forming limit of the nFML during stamping. Hemispherical punch test was carried out to determine the formability and circle grid analysis was used to determine the forming limit diagram (FLD) and failure limit curve (FLC) of the nFML. Range of safety, critical zone where necking and fracture will occur and strain level of the nFML were also plotted in the FLD. The graph revealed that the nFML have a potential to be formed into a complex shapes compared to aluminium sheet. The nFML also able to sustain higher strain before failure showing that the nFML structure can have the potential for better formability characteristics than aluminium sheet. A further analysis of nFML were conducted to determine the water absorption behaviour of the nFML to further study the function analysis in TRIZ method, the humidity caused by rain or mist is one of the main contradiction in order to perform the nFML as car front hood. Besides water absorption and thickness swelling, tensile test was also conducted to determine the effect of water to nFML strength. It is observed that the moisture content has effect on the tensile properties but the nFML has minimal effect on water absorption behaviour. The developed nFML car front hood is 85% lighter and 96% cheaper than steel. This thesis contributes to the current research by identifying the potential of the nFML in the development of automotive components. This research has successfully demonstrated the capability of nFML in the design of car front hood that satisfies the intended PDS through concurrent engineering approach.

ABSTRAK

Tesis ini meneroka penyelesaian untuk meningkatkan kecekapan bahan api ke arah mencapai pengurangan pelepasan CO_2 dengan menggunakan gentian semula jadi logam lamina (nFML) sebagai penutup hadapan kereta. Gentian logam lamina (FML) adalah bahan ringan yang memiliki kelebihan logam dan komposit bertetulang gentian yang mempunyai sifat-sifat fizikal dan mekanikal yang cemerlang berbanding dengan struktur logam monolitik. Sehingga kini, sedikit penyelidikan telah dilaporkan berkaitan dengan nFML. Penyelidikan ini melibatkan pendekatan kejuruteraan serentak dalam pemilihan bahan untuk penutup hadapan kereta nFML dengan menggunakan kaedah Fuzzy VIKOR, menjana penyelesaian inventif melalui kaedah Penyelesaian Masalah Pengendalian Teori (TRIZ) dan pengkaji mengenai kebolehbentukan dan perilaku penyerapan air nFML untuk memenuhi spesifikasi reka bentuk produk (PDS) yang dimaksudkan. Gentian kenaf dan polypropylene telah dikenal pasti sebagai gentian semula jadi dan matriks termoplastik yang sesuai untuk fabrikasi nFML dalam pemilihan bahan penutup hadapan kereta. Pengenalpastian masalah atau percanggahan nFML sebagai sistem penutup hadapan kereta dibina menggunakan kaedah TRIZ; 2 lapisan serat kenaf [0º/90º] komposit bertetulang telah dikenalpasti sebagai konfigurasi optimum untuk komposit bertetulang dalam nFML. Analisis kebolehbentukan telah dijalankan untuk menentukan hadmaksimum kebolehbentukan nFML semasa stamping. Ujian pukulan hemispherikal telah dijalankan untuk menentukan kebolehbentukan dan analisis grid bulatan digunakan untuk menentukan rajah had kebolehbentukan (FLD) dan lengkungan had kegagalan (FLC) nFML. Julat keselamatan untuk pembentukan regangan, zon kritikal di mana lekukkan dan patah akan berlaku serta paras ketahanan nFML juga diplot dalam FLD. Graf mendedahkan bahawa nFML mempunyai potensi untuk dibentuk menjadi bentuk kompleks berbanding lembaran aluminium. nFML juga dapat mengekalkan ketegangan yang lebih tinggi sebelum kegagalan menunjukkan bahawa struktur nFML boleh mempunyai potensi untuk ciri kebolehbentukan yang lebih baik daripada lembaran aluminium. Analisis seterusnya untuk nFML dijalankan untuk menentukan kelakuan penyerapan air bagi nFML berdasarkan kepada analisis fungsi melalui kaedah TRIZ iaitu kelembapan yang disebabkan oleh hujan atau kabus adalah salah satu percanggahan utama untuk melaksanakan nFML sebagai penutup hadapan kereta. Selain penyerapan air dan pembengkakkan ketebalan, ujian tegangan juga dijalankan untuk menentukan kesan air kepada kekuatan nFML. Telah diperhatikan bahawa kandungan lembapan mempunyai kesan pada sifat tegangan tetapi nFML mempunyai kesan minimum terhadap tingkah laku penyerapan air. Penutup hadapan kereta nFML adalah 85% lebih ringan dan 96% lebih murah daripada keluli. Tesis ini menyumbang kepada penyelidikan semasa dengan mengenal pasti potensi nFML dalam pembangunan komponen automotif. Penyelidikan ini telah berjaya menunjukkan keupayaan nFML dalam reka bentuk penutup hadapan kereta yang memenuhi PDS yang dimaksudkan melalui pendekatan kejuruteraan serentak.

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AA	-	Aluminium Alloy
ABS	-	Acrylonitrile Butadiene Styrene Copolymer
ADR	-	Accord DangereuxRoutier
AHP	-	Analytical Hierarchy Process
Al	-	Aluminium
Al-Mg	-	Aluminium-magnesium
ANP	-	Analytical Network Process
ANCAP	-	Australia New Car Assessment Programme
ANOVA	-	Analysis of Variance
ARALL	-	Aramid Fibre Reinforced Aluminium Laminate
ARAS	-	A new Additive Ratio Assessment
ASTM	-	American Society for Testing and Materials
CAJRALL	-	Carbon-Jute Reinforced Aluminium Laminate
CAJRMAL	-	Carbon-Jute Reinforced Magnesium Laminate
CARALL	-	Carbon Fibre Reinforced Aluminium Laminate
CFC	-	Carbon/Flax/Carbon
CFRP	-	Carbon Fibre Reinforced Polymer
CH_4	-	Methane
CMVSR	-	Canadian Motor Vehicle Safety Regulations
CO_2	-	Carbon dioxide
COPRAS	-	Complex Proportional Assessment
DEMATEL	-	Decision Making and Evaluation Laboratory
DMA	-	Dynamic Mechanical Analysis
EC	-	Commission Regulation
EC	-	Estimate Cost
ECE	-	Economic Commission for Europe
ECQFD	-	Environmentally Conscious Quality Function Deployment

EEVC/WG	-	European Enhanced Vehicle Safety Committee/ Pedestrian Safety
EU	-	European Union
ELECTRE	-	Elimination and et choice translating reality
EVAMIX	-	Evaluation and mixed criteria
FCF	-	flax/carbon/flax
FLC	-	Failure Limit Curve
FLD	-	Forming Limit Diagram
FML	-	Fibre Metal Laminate
FMVSS	-	Federal Motor Vehicle Safety Standards
GRA	-	Grey Relational Analysis
G/G/G	-	glass/glass/glass
G/K/G	-	glass/kenaf/glass
GLARE	-	Glass Fibre Reinforced Aluminium Laminate
GTR	-	Global Technical Regulations
GPa	-	Young's modulus
g/cm^3	-	Density
gCO_2/km	-	grams of carbon dioxide per kilometre
HDPE	-	High Density Polyethylene
HSS	-	High Strength Steel
IOWA	-	Induced Ordered Weighted Averaging
IDA	-	Institute for Defense Analyses
J/m	-	Impact strength
KGK	-	kenaf/glass/kenaf
KKK	-	kenaf/kenaf/kenaf
kg	-	Kilogram
kN	-	Kilo newton
kJ/m^2	-	Charpy impact strength
LDPE	-	Low Density Polyethylene
MABAC	-	Multi-Attributive Border Approximation area Comparison
MCDM	-	Multi Criteria Decision Making
MPV	-	Multipurpose Vehicle
MPa	-	Tensile strength

mm	- millimetre
m/s	- Metre per second
mm/min	- Millimetre per minute
nFML	- Natural Fibre Metal Laminate
N_2O	- Nitrous oxide
NHTSA	- National Highway Traffic Safety Administration
NaOH	- Sodium Hydroxide
NaCl	- Sodium Chloride
OCRA	- Operational Competitiveness Rating Analysis
ppm	- Parts per million
PDS	- Product Design Specification
PF	- Phenol Formaldehyde
PP	- Polypropylene
PVC	- Poly Vinyl Chloride
POFML	- Palm Oil Fibre Metal Laminate
PLA	- Polylactic Acid
PBS	- Polybutylene Succinate
PROMETHEE	- Preference Ranking Organization Method for Enrichment Evaluations
PS	- Polystyrene
PET	- Polyethylene Terephthalate
QFD	- Quality Function Deployment
SMA	- Shape Memory Alloys
SEM	- Scanning Electron Microscopy
SPIF	- Single Point Incremental Forming
TA	- Titanium Alloy
TC	- Targeted Cost
TRIZ	- Theory of Inventive Problem Solving
TGA	- Thermogravimetric Analysis
TOPSIS	- Technique for Order of Preference by Similarity to Ideal Solution
TAM	- Technology Acceptance Model
TFT-LCD	- Thin film transistor liquid crystal display
UN	- United Nations

USA	-	United States of America
USD	-	United States Dollar
VIKOR	-	Multi Criteria Optimization and Compromise Solution
wt%	-	Weight percentage
^{o}C	-	degree Celsius

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