APPLICATION OF TRIZ TO DEVELOP NATURAL FIBRE METAL LAMINATE FOR CAR FRONT HOOD

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ABSTRACT

This study applies TRIZ method on natural fibre metal laminate as car front hood to generate inventive solutions to reduce vehicle's weight. The increase in greenhouse gasses such as carbon dioxide, methane and ozone in the atmosphere has caused global warming, the implementation of the natural fibre metal laminate as car front hood is expected to enhance the vehicle performance and reduce the gas emission of vehicles which will directly reduce the global warming problem. Fibre metal laminate consists of metal and composite layering which is a lightweight material that takes advantages of metal and fibre reinforced composite. Since there is some limitation in this material, the application of TRIZ method could assist to solve the problem in inventive and effective solutions to utilise natural fibre metal laminate as car front hood. Using the If, Then and But keywords the contradiction of natural fibre metal laminate as car front hood utilisation is identified. These keywords will be translated to the appropriate parameter to identify 40 Inventive Principles which lead to TRIZ solution principles and solution idea could be generated. Two contradictions occur throughout this utilisation, and the specific solution ideas have been gained, through the application of TRIZ method and the two TRIZ solution principles involved to generate specific solution ideas are #35 parameter changes and #1segmentation.

Keywords: teoriya reshniya Izobretatelskikh zadatch (TRIZ), fibre metal laminate (FML), natural fibre, car front hood.

INTRODUCTION

Fibre metal laminate (FML) is a sandwich structure consisting of metal and fibre reinforced composite layers developed at the Delft University of Technology in the 80's. ARALL (Aramid Fibre Reinforced Aluminium Laminate), GLARE (Glass Fibre Reinforced Aluminium Laminate) and CARE (Carbon Fibre Reinforced Aluminium Laminate) are the most commercially available FML. These FMLs are used in aerospace especially in aircraft as a floor, fuselage and wings (Vlot and Gunnink, 2001). FML is a lightweight material that takes advantages of metal and fibre reinforced composite. FMLs have high fatigue resistance, high strength, high impact resistance, low density, high energy absorbing capacity and high fracture toughen (Ferreira *et al.*, 2016).

Numbers of experimentations have been conducted to explore the FML properties. Bikakis *et al.* (2017) studied the ballistic impact response of square clamped fibre metal laminates and monolithic plates consisting of the differentaluminium alloy. Poodts *et al.* (2015) do the experimental characterization for an underwater application using FML. Hariharan and Santhanakrishnan (2016)analyse the FML with aluminium alloy by doing the tensile, flexural and compression test for aircraft structures application. Zhang *et al.* (2017)analysed magnesium based FML, focusing on the effect of surface treatment on the corrosion properties. Zu *et al.* (2017) explore the effect of the temperature and geometrical parameters on mechanical properties of pin loaded FML joints. Lee *et al.* (2014) conducted an analytical evaluation of theuniaxial tensile deformation behaviour of FML based on self-reinforced polypropylene. Zal *et al.* (2017) investigate the effect of temperature and layup on the press forming of polyvinyl chloride-based composite laminates and fibre metal laminates.

Although many researchers have explored FML, however, there are fewer studies of FML based on natural fibre reinforced composite. Since natural fibre has a sustainable life cycle, low density, lightweight, non-toxicity, renewable, biodegradable and low cost (Tong *et al.*, 2017), exploration on natural FML has started to get more attention in recent years. Ishak *et al.* (2016a,b)have studied the potential thermoplastic and natural fibre for FML using the Multiple Criteria Decision Making (MCDM). Sivakumar *et al.* (2016) conducted an impact assessment on oil palm empty fruit bunch FML. Ng *et al.* (2017) investigated fatigue performance of a hybrid FML structure incorporating kenaf and glass fibre. Fazilah *et al.* (2016) studied the different fibre loadings and fibre orientation of the woven kenaf fibre reinforced polypropylene hybrid aluminium composite by determining the tensile properties. Jumaat and Sivakumar (2017) investigated the mechanical properties of different woven orientation and layup of hybrid FML between kenaf fibre and glass fibre. Mohd Ishak *et al.* (2017) determine weight of criteria for natural fibre for fibre metal laminate using Entropy method.

In general investigation on the FML conducted by those researchers were focusing on the mechanical properties of the material. To date, there is no work found in exploring the application of the naturalFML, especially in the automotive field. To apply natural FML as the automotive components, there aremany more studiesrequired since strength and stiffness of natural fibres are low compared to synthetic fibres (Rout *et al.* 2001). TRIZ method could be applied since it is a problem-solving method based on logic and data (Kim *et* *al.*, 2009). TRIZ stands for 'Teoriya Reshniya Izobretatelskikh Zadatch' in Russian which means 'Theory of Inventive Problem Solving'. Many researchers had used this tool to understand and solve problems (Karen Gadd, 2011). Mastura *et al.* (2016) used TRIZ to determine the design concept of a hybrid biocomposite automotive anti-roll bar. Chao and Peng (2016) design the high-efficiency solar electricity of umbrella. Lin and Wu (2016) innovate recycling machine using TRIZ. Hsieh *et al.* (2015) applied TRIZ and Fuzzy AHP (Analytic Hierarchy Process) to develop an innovative design of a new shape for machine tools. Mansor *et al.* (2014) developed a conceptual design of kenaf fibre polymer composite automotive parking brake lever using the integrated TRIZ-Morphological Chart-AHP method. Through case studies mentioned, it shows that the TRIZ method is practical in problem-solving that could lead to innovative solutions. The integration of TRIZ method with other tools also makes this method more convincing in problem-solving. Therefore, the aim of this study is to apply TRIZ method on natural FML as car front hood to generate inventive solutions to reduce vehicle's weight (Figure-1). The implementation of the natural FML as car front hood is expected to enhance the vehicle performance and reduce the gas emission of vehicles which indirectly would reduce the global warming problem.

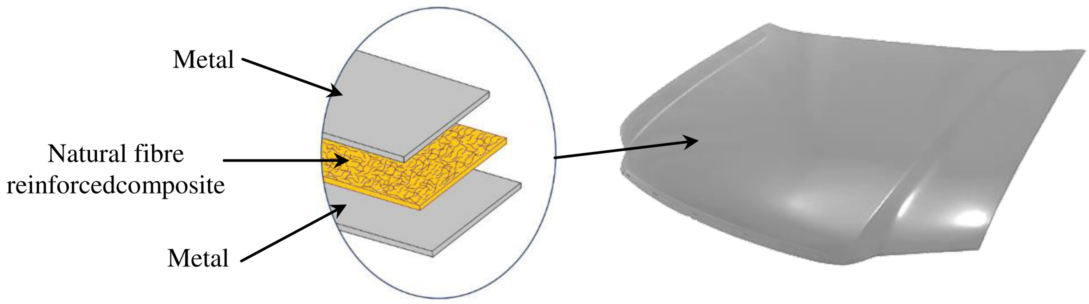

Figure-1. Configuration of natural fibre metal laminate as car front hood.

METHODOLOGY

Developed by Genrich Squlovich Altshuller and his team, TRIZ is a tool for inventive and effective solutions for problem-solving. According to Gadd (2011a,b), steps involved in TRIZ solving method, starts with defining the specific issue; gaps between requirements at all stages of creating and using systems that need a solution for system improvement for faultless operations. Second is to interpret the specific problem into a general problem (e.g. engineering contradiction, physical contradiction, function model, substance field model). Third, based on this general issue, apply the solving principles belonging to TRIZ (contradiction matrix, the system of standard inventive solutions), to determine the general solution. Finally, derive the specific solutions from solving the problem based on the suggested TRIZ general solution

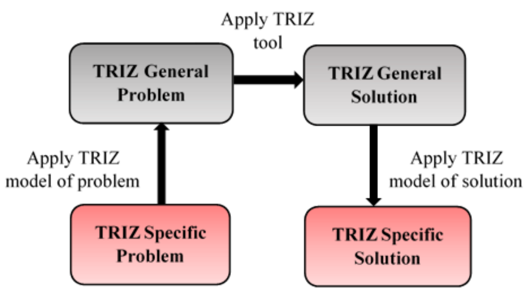

Figure-2. TRIZ problem-solving method (San *et al.*, 2009).

Figure-2, illustrates the TRIZ problem-solving method which classified problems and solutions in seeking correlation that enables a set of generic problem-solving operators (Li, 2010).

FUNCTION ANALYSIS

Function analysis is the first stage of problem analysis which help to describe the system. It helps to identify the interaction between system, subsystem and super system. According to Muenzberg *et al.*, (2014), function analysis is an analytical tool which helps to determine the components of a technical system and the functional relationship between the components where this system can be visualize with simple visual function map. Generally, the function analysis reveal the interactions within all components in the system and any contradictions that may occur during the product function could be detected and further analysis could be done to improve the product functions. Besides, this system also could sort out all the issues faced by the system, and the prioritize problem could be determine.

In this case, the system is car front hood that utilisesnatural FML as the material. Figure-3 shows the function analysis of the natural FML as a car front hood. One of the important function of a front hood is to absorb impact. During collision the front hood will deform its shape while absorbing the impact energy. The second function is to improve the strength and stiffness of natural FML front hood since strength and stiffness of natural fiber are low compared to synthetic fibers. Using TRIZ method, the contradiction in natural FML for car front

VOL. 13, NO. 1, JANUARY 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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hood utilisation will be identified and the specific solution will be proposed.

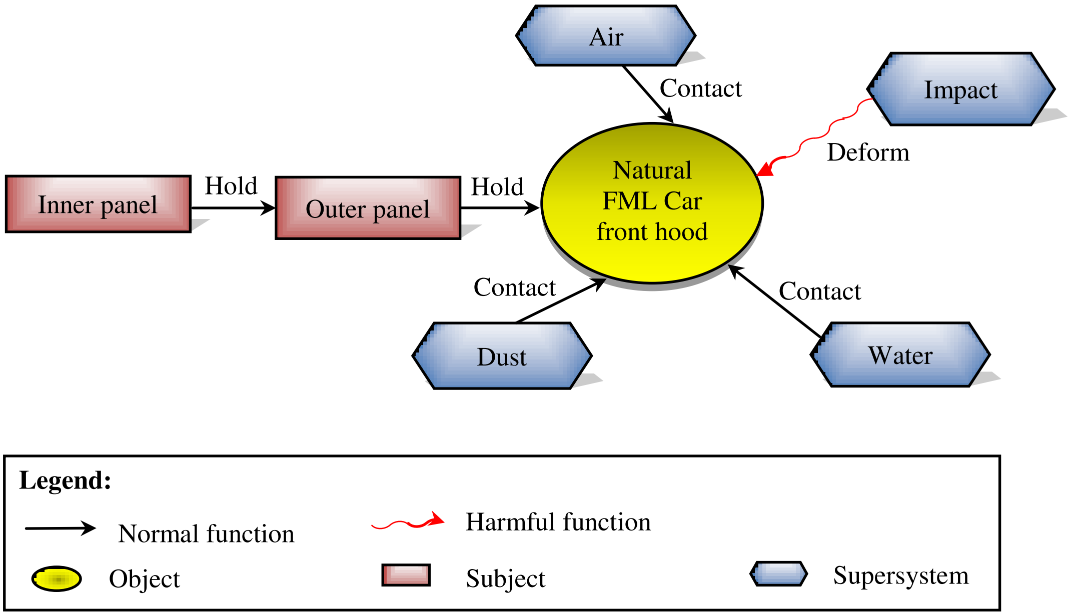

Figure-3. Function analysis of natural FML as car front hood.

APPLICATION OF TRIZ

Using TRIZ method, the contradiction of natural FML as car front hood is identified using If, Then and But keywords that are compatible to the constraint that can be manipulated to acquire the solution where 39 Systems Parameters will be used. Then, the appropriate parameter will be translatedfor the selection of 40 Inventive Principles through the TRIZ contradiction matrix.

If: state what change is made
Then: state what good happens (improving features)
But: state what bad happens (worsening features)

a) Problem statement for Contradiction 1:

If apply a natural fibre composite layering of FML as car front hood,
Then weight reduction of the vehicle could be achieved,
But theshape at the impact point can be deformed due to ability of the structure to absorb the impact energy during collision

b) Problem statement for Contradiction 2:

If apply a natural fibre composite layering of FML as car front hood,
Then weight reduction of the vehicle could be achieved,
But thereliability of the natural FML structure to absorb the impact energy is uncertain

SOLUTION FOR CONTRADICTIONS

Next, the parameters will be referreded to Contradiction Matrix to determine the potential 40 Inventive Principles that suggested by TRIZ. Tables 1 and 2 showed the inventive solution principles that have been recommended by TRIZ method for both contradictions.

Table-1. TRIZ theory solutions for contradiction 1.

Improving features	Worsening features	TRIZ Solution principles
#1 weight of moving object	#12 shape	# 10 preliminary action *# 35 parameter changes* # 14 spheroidality - curvature # 40 composite materials

Table-2. TRIZ theory solutions for contradiction 2.

Improving features	Worsening features	TRIZ Solution principles
#1 weight of moving object	#27 reliability	*# 1 segmentation* # 3 local quality # 11 beforehand cushioning # 27 cheap short-living objects

Through the solution principles suggested by TRIZ, the potential solutions to solve the contradictions could assist to generate ideas. For contradiction 1, solution principle # 35 has been chosen to generate specific solution ideas, while for contradiction 2, solution principle

1 has been chosen to generate specific solution ideas. Tables 3 and 4 showed the design strategy based on identified TRIZ solution principles for both contradictions. According to the design strategy based on the identified TRIZ solution principles, the potential solutions could be applied to generate the specific solution ideas for the contradictions. Figures 4 and 5 illustrated the solution ideas for both contradictions.

Table-3. Design strategy based on identified TRIZ solution principles for contradiction 1.

TRIZ Solution principles	Solution descriptions	Design strategy descriptions
# 35. Parameter changes	Change other parameters	Vary the fibre orientation changes from layer to layer to improve ability of the structure to absorb the impact energy

Table-4. Design strategy based on identified TRIZ solution principles for contradiction 2.

TRIZ Solution principles	Solution descriptions	Design strategy descriptions
#1. Segmentation	Increase the degree of fragmentation or segmentation	Vary the stacking configuration of the composite or metal ply in the FML layering to increase strength to absorb impact energy

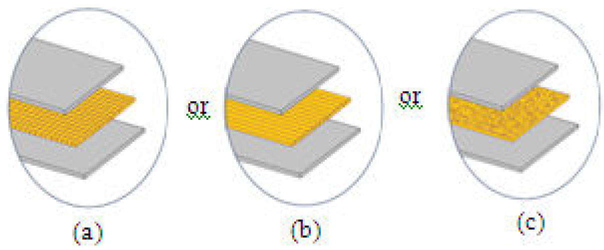

Figure-4. Solution idea for contradiction 1. (a) Woven; (b) Uni-directional;(c) Random.

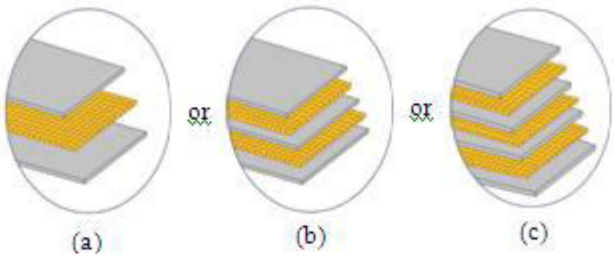

Figure-5. Solution idea for contradiction 2. (a) Stacking 2/1; (b) Stacking3/2; (c) Stacking 4/3.

RESULTS AND DISCUSSIONS

A function analysis has been generated to look into the interaction between each component to analyse the contradiction of natural FML as car front hood. Using the If, Then and But keywords that have been led by the function analysis, the affected or harmful components could be defined and identified and the compatible parameter will be translated to acquire the solutions for each contradiction where 39 systems parameters were used to determine the improving and worsening parameters. Once the parameters are clearly stated, the contradiction matrix was used to identify the relevant inventive principle as listed in 40 Inventive Principles which would guide to solve the problems.

For TRIZ application on natural FML as car front hood, two contradictions may occur during the product function, which are shape and reliability. Through function analysis, contradiction 1havebeen identified, where if apply the natural FML as car front hood, the weight reduction of the vehicle could be achieved, however, the shape at the impact point can be deformed due to the ability of the structure to absorb the impact energy during a collision. Through the application of the TRIZ method, principle # 35 parameter changes are the suggested solution that could solve the problems. The design strategy is by varying the fibre orientation changes from layer to layer to improve the ability of the structure to absorb the impact energy, where fibre orientations that could be implementedare woven, uni-directional or random fibre. According to Jawaid and Abdul Khalil (2011), there arevarious parameter that could affect the strength of the hybrid composite such as fibre content, fibre to matrix interface bonding, and orientation of fibre. Shibata *et al.* (2008) comment that fibre orientation distribution significantly affects the flexural modulus of the composites.

While for contradiction 2, if apply the natural FML as car front hood, the weight reduction of the vehicle could be achieved, however, the reliability of the structure to absorb the impact energy better than actual front hood during collision is unreliable. Using TRIZ method, principle #1 segmentation is the suggested solution that could solve the problems. The design strategy is by varying the stacking configuration of the composite or metal ply in the FML layering to increase strength to absorb impact energy. The suggested stacking are 2/1 (2 layers of metal and 1 layer of natural fibre reinforced composite), 3/2 (3 layers of metal and 2 layers of natural fibre reinforced composite) or 4/3 (4 layers of metal and 3 layers of natural fibre reinforced composite). Studied by Strait *et al.* (1992) showed that stacking sequence was found to have a significant effect on the impact resistance, particularly at higher impact energies. According to Kuan *et al.* (2011), by incorporating the metal layers into the composites could enhance the tensile and impact properties of the composites. Besides, Behrooz *et al.* (2014) indicate that the carrying load by the FML plates decreased after the initiation of failure in the outer metal layer in all layups.

CONCLUSIONS

This study applied TRIZ method on natural FML as car front hood to generate inventive solutions to reduce vehicle's weight. By lowering the vehicle's weight, the fuel efficiency increases and will help to overcome the global warming issues. To implement the natural FML as car front hood is not an easy task since there is some limitation of the natural fibre's strength and stiffness. Therefore, to solve this problem, TRIZ method has been applied to solve contradictions that may occur during utilisation of natural FML as car front hood. By generating the function analysis of the car front hood system, 2 contradictions were determined and TRIZ has suggested the potential solutions to solve the contradictions. Through application of the TRIZ method, principle # 35 parameter changes was selected as the suitable solution for contradiction 1, where the design strategy is by varying the fibre orientation changes from layer to layer to improve ability of the structure to absorb the impact energy, the suggested fibre orientations are woven, uni-directional or random fibre.While for contradiction 2, principle #1 segmentation was selected as the suitable solution. The segmentation strategy is by varying the stacking configuration of the composite or metal ply in the FML layering to increase strength to absorb impact energy eg. stacking 2/1 (2 layers of metal and 1 layer of natural fibre reinforced composite), 3/2 (3 layers of metal and 2 layers of natural fibre reinforced composite) or 4/3 (4 layers of metal and 3 layers of natural fibre reinforced composite).

ACKNOWLEDGEMENT

We would like to acknowledge the Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka and MyBrain15 scholarship by the Ministry of Higher Education of Malaysia (MOHE) for making this study possible.

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