EVALUATION OF CRACK GROWTH BEHAVIOUR ON SANDWICH METAL PANEL USING 2^k FACTORIAL METHOD

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ABSTRACT

This study investigates the crack growth response on sandwich metal panel (SMP) combination of high strength steel (HSS) as faces and magnesium alloy (AZ31B) as core on the light armoured vehicles LAV. Currently, LAV uses a special solid steel which content heavy material that causes the LAV reduce its lifespan performance and limit the movement after shot by ammunition bullets with high impact until the crack starts to form. The main objective of this research is to develop SMP that can provide improvement in terms of life durability compared to existing materials in LAV applications. A crack growth test was done using compact tension, CT by comparing the improvement solid HSS and AZ31B with sandwich metal panel in terms of life durability and energy absorption. Crack growth response investigation focuses on the frequency, $f = 10$ Hz and stress ratio, $R = 0.1$ as control variables. Next, the Design of Experiment of the 2^k factorial method was implemented by applying frequency, f (5 Hz and 10 Hz) and stress ratio, R (0.1 and 0.5) as statistical analysis. Twelve runs were carried out for the sandwich metal panel to obtain an optimum response for the number of life cycles and crack length in the empirical model equation and the best optimal D efficiency obtained. The increment of life cycle on crack growth analysis between HSS and SMP was about 18%, while the life cycle for AZ31B and SMP was about 34%. From the statistical result, an empirical model for the number of cycles has been chosen as optimum values for maximising the number of life durability on SMP at frequency, $f = 10$ Hz and stress ratio, $R = 0.5$. The increment of life cycle using optimum values between HSS and AZ31B with SMP was more than 60%. Thus, the potential of SMP to be replaced as an improvement in life durability for the light armour vehicle, LAV application has been verified.

ABSTRAK

Kajian ini mengkaji respon pertumbuhan retak pada panel logam sandwic (SMP) gabungan antara keluli berkekuatan tinggi (HSS) sebagai material lapisan luar dan aloi magnesium (AZ31B) sebagai lapisan teras pada kenderaan berperisai ringan, LAV. LAV kini menggunakan keluli pejal khas yang mengandungi bahan berat sebagai kandungan utamanya menyebabkan prestasi jangka hayat LAV berkurang dan pergerakannya terbatas selepas di tembak oleh peluru berkelajuan tinggi sehingga terjadinya retak. Objektif utama penyelidikan ini adalah untuk membangunkan SMP bagi menambahbaik material sedia ada pada LAV khusunya dalam aspek ketahanan jangka hayat. Ujian pertumbuhan retakan dilakukan menggunakan keluli ketegangan padat (CT), dengan membandingkan ketahanan jangka hayat dan serapan tenaga diantara bahan HSS dan AZ31B terhadap SMP. Respon pertumbuhan retakan dikaji dengan menetapkan nilai frekuensi, f = 10 Hz dan nisbah tegangan, R = 0.1. Rekabentuk eksperimen kaedah faktorial 2k telah menggunakan nilai f (5 Hz & 10 Hz), manakala R (0.1 & 0.5) pada analisa statistik. Sebanyak 12 ujian telah dijalankan terhadap SMP bagi mendapatkan bilangan jangka hayat dan panjang retakan yang optimum dalam model empirikal. Melalui kaedah ini, nilai optimum keberkesanan D diketahui. Peningkatan jangka hayat bagi analisis pertumbuhan retakan diantara HSS dan AZ13B terhadap SMP adalah sebanyak 18% dan 34%. Analisa statistik menunjukan model empirikal kitaran jangka hayat telah dipilih dalam menentukan nilai optimum bagi maksimumkan jumlah jangka hayat terhadap SMP, iaitu pada nilai f = 10Hz dan R = 0.5. Dapatan nilai optimum bagi peningkatan jangka hayat antara HSS dan AZ13B terhadap SMP melebihi 60%. Justeru, potensi SMP untuk menggantikan bahan LAV dalam meningkatkan jangka hayat berjaya dibuktikan.

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The Examination Committee has met on 27th Oct 2021 to conduct the final examination of Abdullah Helmi Bin Isahak on his degree thesis entitled ‘Evaluation of Crack Growth Behaviour on Sandwich Metal Panel Using 2^k Factorial Method’.

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TABLE OF CONTENTS

APPENDIX A

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
AZ31B	Magnesium Alloy
CAL	Constant Amplitude Loading
CT	Compact Tension
CG	Crack Growth
DOE	Design of Experiment
FEA	Finite Element Analysis
HCF	High Cycle Fatigue
HSS	High Strength Steel
LAV	Light Armour Vehicle
LCF	Low Cycle Fatigue
LHDCC	Lightweight High Ductility Cement Composite
MinDef	Ministry of Defence Malaysia
RHA	Rolled Homogeneous Armour
SMP	Sandwich Metal Panel
SMSP	Sandwich of Mild Steel Panel
SAMSP	Sandwich of Aluminium with Mild Steel Panel
UTS	UltimateTensile Strength
UHPC	Ultra-High-Performance-Concrete
UPNM	Universiti Pertahanan Nasional Malaysia
VMS	Von Mises Stress
YS	Yield Strength

LIST OF SYMBOLS

a	Crack Length
C	Material Constant (y-axis intercept)
da/dN	crack growth rate
E	Modulus of elasticity
ε	Strain
f	Frequency
Hz	Hertz
ΔK	Stress Intensity
ΔK_{th}	crack growth threshold
kN	Kilonewtons
ΔL	Change Length
L_0	Initial Length
L	Final Length
m	Material Constant (gradient of slope)
mm	Millimeter
Mpa	Megapascal
N	Newton
N	Total Number of Cycles
N_f	Number of Cycles to Failure
P	Applied Load
%	Per cent sign
R	Stress Ratio
W	Width
t	Thickness
σ_{max}	Maximum Stress Value
σ_{min}	Minimum Stress Value
$\Delta\sigma$	Cyclic Stress Range
$\Delta\sigma_a$	Cyclic Stress Amplitude
σ_m	Mean Stress
σ_{UTS}	Ultimate Tensile Strength
σ_{YS}	Yield Stress

CHAPTER 1

INTRODUCTION

1.1 Background Research

The application of crack growth on sandwich metal panel (SMP) is gaining attention in the field of the military, especially in the construction of light armoured vehicles (LAV). During service, the technical components that make up a movement mechanism are often exposed to cyclic or variable stress. Relevant examples often relate to the area of automotive research, such as military operation vehicles, which are an example of fatigue-prone constructions [1]. The development of light armoured vehicles (LAV) poses the possibility that the country will be able to carry out military operations in a more efficient and less risky way, especially when shot by high-velocity ammunition bullet, which will reduce its operability performance [2]. When metal and composite are exposed to a specific number of cyclic loadings, most fatigue failures in engineering structures are caused by exposure to fluctuate loading. To maintain the components' safety and integrity, a thorough knowledge of material behaviour is required. The amount of stress or strain cycles that a material can take before failing is often referred to as fatigue life [3, 4]. The number of loading cycles before the fracture forms may be used to estimate a component's service life [5].

The railway axles in Europe collapsed during operation in the mid-nineteenth century, prompting this important research of fatigue failure. Fairbairn in the United Kingdom and Wöhler in Germany performed laboratory tests in the early 1860s and reported their findings as graphs of applied stress, S, against the number of cycles to failure, N in their work [6]. Similar (S-N) curves have been utilised to design components and structures for metal and composite to prevent fatigue failures as a result of their research. Geometric models [7], microstructure and grain sizes [8, 9], surface finish through modelling works [10], loading conditions related to both constant and variable amplitude [11, 12], the environment through corrosion [13], and temperature [14, 15] are just a few of the factors that affect the fatigue life of engineering components. The fatigue damage may even further reduce the structural resistance with the presence of different kinds of imperfections, leading to increased local stresses and accelerated crack initiation and propagation. Crack growth (CG) is an important parameter that needs to be considered.

It is generally acknowledged that fatigue and crack growth must be taken into account in the design and failure analysis. The crack path must be determined as part of the full solution to the fatigue and crack growth issue [16]. The variables that govern the path followed by fatigue and crack growth are not entirely understood. Crack growth is a basic fracture mechanics concept that includes crack surface displacement, which is calculated using the trend number of fractures, a, and the number of cycles, N. The crack surfaces move relative to one another when stress is applied to a cracked body, and there are three modes of crack surface displacement [17, 18]. These include: Mode I, in which opposing crack surfaces move straight apart; Mode *II*, in which crack surfaces move perpendicular to the crack front; and Mode *III*, in which crack surfaces move parallel to the crack front [18].

Moving forward with technology, new lightweight material should be introduced in sandwich metal panel development to observe the crack growth behaviour [19]. Given that metal structures are often exposed to fatigue stress, it is necessary to analyse the crack growth behaviour of sandwiched metal panels. Typically, a sandwich metal panel has more than two layers: a low-density core and a thin skin layer connected to either side. Sandwich metal panels are utilised in applications that need a high degree of structural strength while being lightweight [20]. Many researchers in the past focused on areas associated with the sandwich metal panels due to their relatively poor resistance impacting loading application [21, 22]. However, not many researchers studied crack growth behaviour on a sandwich metal panel. Admittedly, the sandwich metal panel can reduce the weight of material without compromising its application. The advantage of the sandwich metal panel in crack growth application is that delamination always occurs at the top layer during rugged movements or fluctuating loads [23].

1.1.1 Application of Sandwich Metal Panel

A sandwich metal panel (SMP) is a kind of laminated material that is unique. The high stiffness- and strength-to-weight ratios are the primary advantages of this lay-up. Integrated functions such as thermal insulation, buoyancy, and, in certain instances, strong acoustic insulation, high energy absorption capabilities, and integrated production are its additional benefits [24]. In an SMP, the faces will work together to create an effective stress pair counteracting the external bending moment, according to Zenkert D. [25]. The core protects the faces from buckling and wrinkling by resisting shear. The connection between the faces and the core, particularly in aviation applications, must be strong enough to withstand the shear and tensile pressures created between them.

The aviation industry is becoming more interested in the SMP idea and structures, which have been used in a wide range of applications. Cabin flooring in civil aircraft [26], control surfaces, landing bay doors [27], helicopter rotor blades and fuselages [28], satellite antennas, and solar panels are all examples of aeronautical applications. Moreover, the SMP idea has become one of the main construction methods for small and medium-sized ships in the boat building business [31]. SMP architecture is currently used for the primary structure of even bigger lightweight passenger ferries with built-in metal to reduce weight at the higher levels and increase the ship's seaworthiness [32]. SMP has emerged as a promising design idea for railway and subway cars, allowing for greater stiffness and, as a result, higher vibration eigenfrequencies [33]. Since they provide integrated thermal insulation in the load-carrying structure, truck tankers for liquid fuels, milk, juice, and other substances also have a built-in SMP design [34].

1.1.2 Potential of Core in Sandwich Metal Development

These types of core designs are used due to their properties of lightweight, good impact resistance, and good energy absorption [35]. However, there are still limited studies on metal-based sandwich metal panels. There is a type of sandwich metal panel that uses a solid plate as their main core for the sandwich metal panel. For core material, the use of aluminium alloy prevails in various engineering fields [36]. However, J. Song et al. [37] reported that magnesium alloy has emerged as one of the materials with the potential of replacing aluminium alloy, thus becoming an alternative material for a core material in sandwich metal panels. Magnesium alloy has similar properties with that of aluminium alloys, such as formability and mass, making it a potential candidate for use in large-sized manufacturing industries, such as railway construction and military protection vehicle production [37]. However, there are some limitations on its core design, such as small adhesive areas and hollow design, both of which may affect the delamination and cracking rate. On top of that, lower core density may weaken the structural integrity of the sandwich metal panel. Therefore, for heavy applications such as light armoured vehicles, it is necessary to propose a core design that not only can sustain the high velocity impact but have a better rate of delamination under high compression or tension force.

1.2 Problem Statement

Special solid material for applications in the maritime, aviation, and automotive sectors are the most essential element of any product in the modern age. The presence and development of cracks produced by fatigue failure and crack propagation under repeated loading are a concern in most solid material constructions [4,10]. Due to its great material strength, the light armoured vehicle (LAV) plays a major part in the protective action [38]. The introduction of new materials and advancements to existing materials used to build LAV has resulted in improved protection and a decrease in the LAV's weight throughout history [2, 39]. However, it should be noted that the significant weakness of LAV is due to high impact of ammunition bullets with high velocity until the crack starts to form under fluctuating movements, which will reduce its life durability performance and operability.

As a result, a new lightweight sandwich metal panel development should be developed to replace the current solid material utilised in LAV. Because LAV is often exposed to cyclic stress conditions, a crack growth behaviour study for sandwiched metal panels is required, particularly on its performances in terms of constant amplitude loading. The appropriate material involving lightweight material concerning the crack growth behaviour needs to be established. The use of magnesium alloy materials is important as it has several advantages in lightness and shock absorption properties [40]. As a sandwich metal panel, its weight may pose an issue, especially in terms of maneuverability in the war zone and rescue operations. However, the existing solid material in LAV has shortcomings in terms of strain and energy absorption for crack growth behaviour application. These shortcomings need