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30th International Symposium on Space
Technology and Science

服務機關：國防大學理工學院動力及系統工程系

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摘要

本次參加之國際研討會為第三十屆太空科技與科學國際研討會(30th International Symposium on Space Technology and Science (ISTS)，參與會議的論文發表者及聽講者(包含學者教授、研究生、產業界研究人員)超過 1,000 名，遍及世界各國，研究領域十分廣泛，研討會領域包括太空技術，太空科學，航天醫學、太空政策和法律的最新研究和發展信息，促使從事太空活動研究領域的專家之間的合作。這次會議提供不同區域學者及業界代表面對面的交流機會，將新的研究方法與應用經驗相互觀摩學習，可進一步建立業務或研究關係，及尋找未來合作的夥伴，並期望能對相關領域的最新科學知識交流有所貢獻。

本次會議投稿篇數為 1,000 餘篇，學術討論範圍計有：化學推進和吸氣式發動機、材料結構、航天動力學，航空導航與控制、流體動力學和氣動熱力學、航天運輸、微重力科學與技術、熱控、衛星通信，廣播和導航、科學和技術促進人類與機器人太空探索、地球觀測、太空生命科學、航天動力系統、太空環境和碎片、系統工程和信息技術、航天教育和推廣為全民利益、太空法律、政策和國際合作、安全與任務等 20 項主軸，極為豐富。

我與研究生們此行共發表兩篇論文：其一為“形狀記憶合金溫度、預應變、體含量效應對形狀記憶合金強化複材板承受低速撞擊的影響(Temperature, Prestrain and Volume Fraction Effect of Shape Memory Alloy Reinforced Composite Laminates under Low Velocity Impact)”，其二為“Al₂O₃/ZrO₂ 功能梯度陶瓷材料設計與抗衝擊分析(Design and Impact Resistant Analysis of Functionally Graded Al₂O₃-ZrO₂ Ceramic)”，參與學者積極提問，討論熱烈，此行除參與者能吸取新知外，經由與國外學者交流，可增廣見聞，有助於未來教學研究之精進。

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目的

- 1.赴日本神戶參加第三十屆太空科技與科學國際研討會，發表研究成果。
- 2.與國際學者進行學術交流。
- 3.觀摩日本航太工業的發展。

過程

此次研討會於 7 月 4-10 日假日本兵庫縣神戶市國際會議中心(Kobe International Conference Center)舉行。會議中心非常接近神戶港，神戶港有 130 年歷史，也是日本國內首屈一指的大型船舶出入停靠的國際港，神戶市的發展和港口密切相關，神戶的鋼鐵、造船業結合中小型的基礎科技公司而有蓬勃的發展。神戶及兵庫縣地區也凝聚了包括製造航空與太空飛行器組件很有競爭力的航天工業。並且今年是神戶大地震發生滿二十周年，此次會議選擇在神戶舉行，個人認為有其深意。

大會以 Space Voyage- Frontier for Better Life on Earth 為標題，計安排有大會演講、論文發表、控制系統設計競賽、學生會議、展覽以及大會安排的參觀神戶大學和觀遊神戶港等活動。7 月 4 日 1000-1700 時開始接受與會人員報到。7 月 6 日 0900-1000 時為大會開幕式，由 Mr. Kazuo Tachi 主持開幕。當晚 1900 時有 ISTS 開幕歡迎宴會，並由兵庫縣副縣長金澤和夫主持開幕致詞，參與開幕貴賓計神戶市副市長、ISTS 委員會會長、宇宙航空研究開發機構理事長、日本航空宇宙學會會長等等...。並準備精緻自助式餐點、祝酒詞和日本當地民俗表演，另介紹和提供當地名產清酒和神戶牛排，現場氣氛熱烈，與會者交流互動頻繁，歷時兩個半小時結束。

7 月 7 日開始依大會規劃之場地就各議題實施分組論文發表與意見交流。

7 月 8 日由研究生 Ying-Chih Ling 上台發表“Temperature, Prestrain and Volume Fraction Effect of Shape Memory Alloy Reinforced Composite Laminates under Low Velocity Impact”。形狀記憶合金為先進材料之一，將形狀記憶合金與 Kevlar 纖維相結合此創新研究雖然在震動領域已有一些研究，但對於抗衝擊方面並無太多之著墨，此研究介紹智能混合複合材料板嵌入形狀記憶合金（SMA）絲在低速衝擊下的分析，以形狀記憶合金之溫度、預應變及體積含量為設計參

數。SMA 線被嵌入到複合材料疊層板中並與整體疊層結構相結合之力學模型，須重新計算整體的材料本構關係。使用疊層板理論、第一剪切理論及最小能量法，求解混合複合材料板抗衝擊之吸收能量，藉以分析 SMA 對纖維疊層複材板結構對抗衝擊性能的影響，採用變異數分析（ANOVA）參數的顯著性。分析結果顯示可以有效地提高混合複合材料疊層板的抗衝擊性能。此一先進材料結構設計概念，強化了結構的抗衝擊性能，達成提升結構的承載效益。

7月9日由研究生Chin-Yu Huang發表“Design and Impact Resistant Analysis of Functionally Graded $\text{Al}_2\text{O}_3\text{-ZrO}_2$ Ceramic”。太空中的航天器、載具和衛星在抗衝擊防護設計上主要在於輕量化、低成本、易製程，故以「梯度化」作為材料的設計和結構控制為當前重要的新科技。功能梯度材料(FGM)是指構成材料的要素(組成、結構)沿厚度方向由一側呈連續變化，進而使材料的性質和功能也成梯度變化的新型材料。本研究以粉末冶金法製作 $\text{Al}_2\text{O}_3\text{-(0、10、20、30 Wt.\%)ZrO}_2$ 功能梯度陶瓷複合材料，背板搭配6061-T6鋁合金，在等厚度或固定面密度下設計功能梯度陶瓷複材板、多層陶瓷複材板和陶瓷複材板。彈道實驗以NIJ IV規範使用0.3吋穿甲彈測試三種複材板，可分析梯度陶瓷結構在高速撞擊下，在層間有界面和無界面之影響。且配合LS-DYNA有限元素軟體，模擬各種複材板在高速撞擊下之梯度結構應力傳遞和破壞模式，經實驗得知功能梯度陶瓷複材板具有最佳的抗彈能力，梯度結構受高速撞擊後，由於拉伸波導致陶瓷迅速斷裂，經SEM觀察層與層之界面未發生脫層，因為降低脫層現象可減少衝擊波在層間界面上產生的反射拉伸波，而減緩陶瓷斷裂的產生。故功能梯度結構的材料設計和製程，可避免層與層 間複雜黏著方式、匹配因素，降低衝擊波導致層與層間脫層現象，增加抗彈能力。

神戶港是神戶市的特定重要港灣，為日本主要的國際貿易港之一，於 1868 年 1 月 1 日開港，現在已成為重要的觀光港口。神戶港在明治時代便成為外國人居留的地區，所以擁有充滿了異國風情的生活區，現在均保留下來並開放參觀，成為很受歡迎的旅遊地，日本稱之為“異人館”。神戶港附近一帶被稱讚為「東洋第一美麗的居留(租借)地」，這裡保存著許多復古又摩登的近代建築物，它們現仍被做為餐館和咖啡廳使用著。神戶塔矗立在神戶港旁，造型如鼓狀非常獨特，已然成為神戶的地標，塔高 108 公尺，夜間閃爍著霓虹燈光，搭配周邊的商場、摩天輪以及大型飯店已成為觀光客必到的觀賞夜景之處。此行至神戶港並搭乘協奏曲號郵輪出海巡遊約一個半鐘頭，港灣夜景盡收眼底，美不勝收，船行至可遠眺明石大橋處折返，「明石大橋」連接淡路島和神戶市，全長 3911 米，是世界最長的吊橋。別名又叫「珍珠橋」，

這個愛稱的由來是大橋的電燈照明就像一條珍珠項鍊一樣，燈火顏色有多種的變化。

從此次研討會議程及活動的安排，尤其從歡迎晚宴上就可看出主辦單位計畫的周詳與細心，既盡了地主之誼，同時也展現出他們民族與地方的特色，此外日本都市的整齊清潔，國民的熱心有禮，工作的程序態度，是有值得我們借鏡之處。

心得及建議

日本太空科技與科學國際研討會(ISTS)乃國際間航太方面知名會議，兩年舉辦一次，參與學者遍及世界各國，學術討論分為:航太技術、科學、醫學、政策和法律等不同議題，涵蓋領域極為豐富，可透過此會議將研究成果發表於國際，並與相關研究人員交流甚至洽談合作，是該研討會的目的也是參與者最大的收穫。

日本在航太領域的研究發展居於世界領先國家之一，經由此次研討會的接觸，深深體會航太工業乃尖端科技之呈現，涵蓋的專業十分廣泛，日本在此領域的扎根很深，學界業界的合作也很緊密，從他們發表的一些研究成果可窺知一二。我國在經國號戰機問世之前確實也組成了很好的研究團隊，整合人才與資源，也累積了可貴的經驗與能量，只因後續無大型計畫支撐，研發能量無法再延續，殊為可惜。會中也巧遇來自交通大學的吳教授，他們跨校組成了一個團隊，研究固液態混合火箭，射程上看 100 公里，他們的研發經費部分也得靠募款獲得。航太科技是做尖端的研究，不能僅以市場需求考量，政府可以前瞻的規劃，整合優秀的人才，給予足夠的支持，或可讓我國在此領域不致落後領先國家太多，否則尖端科技發展永遠受制於人。冀望能在關鍵技術與創意上與國際相接軌，並延伸至國內的相關產業及研究方向上，藉以提高我國之競爭力。

以學習的態度參加此次國際研討會，深深感覺教學與研究所擔負的重大責任；看到國際間各學者最近研究成果，對材料材質改善、量測技術、性能提升，設計創意等都不遺餘力，個人認為應多鼓勵我國相關學者與研究人員參加類似之國際交流會議，讓從事科技研究人員拓展視野、得到更多的啟發，期能立足於競爭的世界舞台。同時，深感英文能力表達之重要性，此後亦當持續鼓勵研究生參加國際研討會，以培養其表達與溝通的能力。

附件一：發表論文簡報之一

30th International Symposium on Space Technology and Science

Design and Impact Resistant Analysis of Functionally Graded $\text{Al}_2\text{O}_3/\text{ZrO}_2$ Ceramic

Chin-Yu Huang

School of Defense Science, Chung Cheng Institute of Technology, National Defense University, Taiwan

C.C.I.T. N.D.U. TAIWAN

Introduction

- Functionally graded materials (FGMs) can **reduce the delamination and the effect of the reflection waves** under impacting.
- FGMs are materials which change their composition, constitution or structure continuously along the direction of thickness, the property and function of those materials appear a changeable gradient feature.

C.C.I.T. N.D.U. TAIWAN

Contents

- Introduction
- Materials selection and processing
- Ballistic test
- Stress Wave Theory
- ANSYS/LS-DYNA Numerical Simulation
- Results and Discussion
- Conclusion

C.C.I.T. N.D.U. TAIWAN

Introduction

The Application of FGM :

- Aeronautics and astronautics
- Electronics
- Nuclear energy
- Optics
- Biomedicine
- Military

Since 2001, the U.S. Department of Defense has allotted a large yearly budget to FGM research.

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Introduction

- Humans have deployed various spacecraft, satellites, and rockets into space, generating considerable amounts of space debris.
- Most of the debris is burnt up as it passes through the atmosphere, residual debris still remains in space.
- The speed of space debris in orbit can reach more than 10 km/s, and a collision with operational equipment can cause destruction to equipment and loss of astronauts' lives.
- Therefore, their **impact resistance and protection abilities must be improved.**

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Materials selection and processing

- Similar **thermal expansion coefficients and sintering conditions** is crucial.
- Powder metallurgy sintering was used to create a four-layer $\text{Al}_2\text{O}_3/\text{ZrO}_2$ FGM at a sintering temperature of 1550 °C.

Ceramics	α (10 ⁻⁶ /°C)	D ₅₀ (μm)	Relative density (%)	Sintering T (°C)	vol. %			
Al_2O_3	8.6	44	99.4-99.8	1550	100	90	80	70
3YSZ	10.1	17.9			0	10	20	30

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Introduction

The research is faced with problems of ceramic composite in impacting :

- The **variations in the elastic modulus, hardness, and density between a ceramic plate and a tough plate.**
- mismatched adhesives are used.**
- Interlayer delamination.**
- The creation of a mathematical model for sandwich structures or multilayer structures.

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Ballistic test

- Regular hexagons with a side length of 60 mm.
- 6061-T6 Al 200 mm × 200 mm × 1 mm.
- Adhesive-Epoxy resin.
- Areal density of ceramics 4.64 g/cm² and the thickness 11 mm (without the adhesive layer and rear plate).

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Ballistic test

- 0.30" armor-piercing bullets
- NIJ IV standard
- the initial velocity is 868±15 m/s.

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Results and Discussion

Stress wave analysis

MCM Interface

	I	II	III	IV	V	VI
E	-0.99468	0.99472	-0.99473	0.99475	-0.99475	0.99478
Reflection coefficient	0.00531	1.99472	0.00527	1.99475	0.00524	1.99478

FGM Interface

	I	II	III	IV	V	VI
E	0.00409	0.00314	0.00225	0.00225	0.00225	0.00225
Reflection coefficient	1.00409	1.00314	1.00225	1.00225	1.00225	1.00225

$\sigma_r = F \sigma_i$
 $\sigma_t = T \sigma_i$

- The transmission and reflection intensity increased with the transmission and reflection coefficient.
- The adhesive layer effect in the MCM also resulted in a dramatic increase or decline in the transmission and reflection intensity.
- By contrast, the reflection and transmission intensities of the FGM decreased.

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Stress Wave Theory

The dissimilar wave impedance of the two media creates a reflection and transmission condition of the stress wave on the interface between the two media.

- $\rho_2 C_2 > \rho_1 C_1$, $F > 0$, $T > 1$, the compression wave (tensile wave) is reflected as the compression wave (tensile wave).
- $\rho_2 C_2 < \rho_1 C_1$, $F < 0$, $0 < T < 1$, the compression wave (tensile wave) is reflected as the tensile wave (compression wave).

$$F = \frac{(\rho_2 C_2) - (\rho_1 C_1)}{(\rho_2 C_2) + (\rho_1 C_1)}$$

$$T = \frac{2(\rho_2 C_2)}{(\rho_2 C_2) + (\rho_1 C_1)}$$

$$\sigma_r = F \sigma_i$$

$$\sigma_t = T \sigma_i$$

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Results and Discussion

Stress wave analysis

Because the FGM displayed no adhesive layer effect, it showed that the level of cracking was less severe in the FGM, so the ceramic cone area formed in the FGM by the impact was complete.

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ANSYS/LS-DYNA Numerical Simulation

A 1/4 model is used for establishing the ceramic composite plate model. The thickness of the adhesive layer is 0.5 mm.

- Adhesive-MAT_PLASTIC_KINEMATIC(No. 3)
- Ceramic-MAT_JOHNSON_HOLMQUIST_CERAMICS(No. 110)
- 6061-T6-MAT_ELASTIC_PLASTIC_HYDRO(No. 10)

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Results and Discussion

Microstructural analysis

- The reflection tensile stress can be reduced and declined delamination in the FGM.
- The transmission wave penetrates the adhesive layer and causes the ceramic to rapidly crack.

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Results and Discussion

Results of experiment and simulation

Under the equal areal density, the absorptive energy in the FGM increased only by 1.61% compared with that in the PCM, but the FGM volume decreased by 7.3%.

Under the equal thickness, although the weight in the FGM increased by 18.1% compared with that in the PCM, the absorptive energy in the FGM substantially increased by 7.8%.

Ceramics	Areal density (g/cm ²)	Thickness (mm)	Average residual velocity (m/s)	Average absorptive energy (J)
FGM	4.64	11	259	33.89
MCM	4.64	11	574	2017
PCM	4.64	11.8	288	3285
Experiment	3.93	11	350	3108

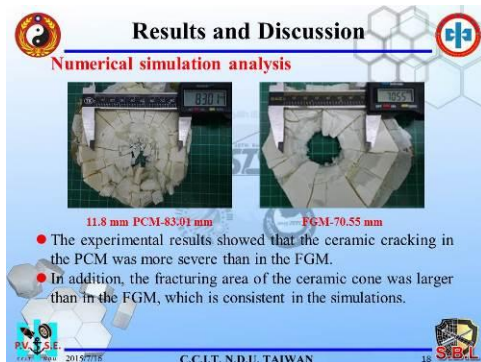
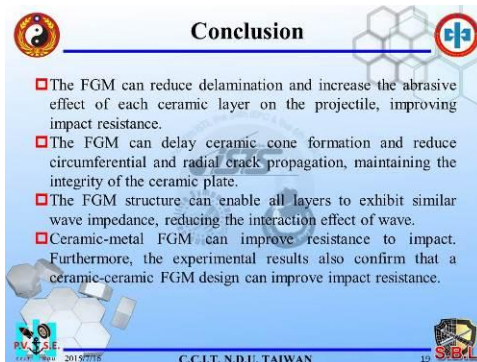
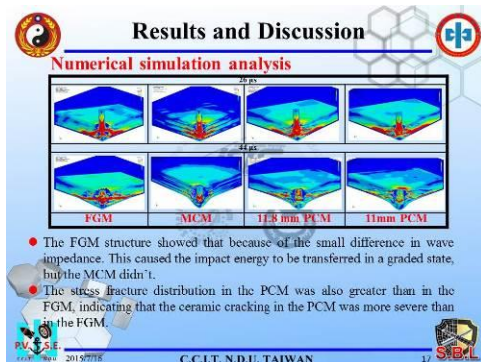
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Results and Discussion

Numerical simulation analysis

- The distribution of the stress exerted on the second ceramic layer plate of the MCM was wider than on the FGM (red area).
- This phenomenon leads to the second ceramic plate damaged by the transmission wave before the projectile reaches the second layer.

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發表論文簡報之二

Temperature, Prestrain and Volumetric Effect of Shape Memory Alloy Reinforced Composite Laminates under Low Velocity Impact

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2015/7/17 C.C.I.T. N.D.U. Taiwan (R.O.C.)

Contents

- Introduction
- Constitutive Equation
- The Energy Absorption of SMA Reinforced Laminated Structure
- Numerical Example
- Results and Discussion
- Conclusions

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Introduction

- Impact damage is one of the major problems.
 - the lack of the thickness reinforcement
 - In particular : aerospace structure
 - Result in : delamination, indentation or outright failure.

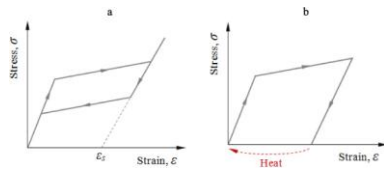
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Introduction

- One of the possible solution to impact damage
 - Embed the SMA wires inside the composites
- There are two characteristics of shape memory alloy
 - superelastic
 - shape memory effect

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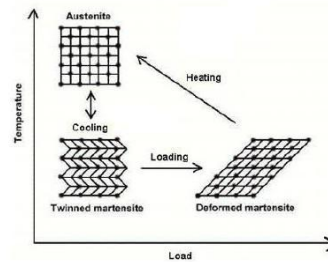
shape memory alloy



(a) superelastic
(b) shape memory effect

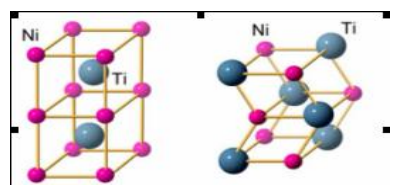
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shape memory effect



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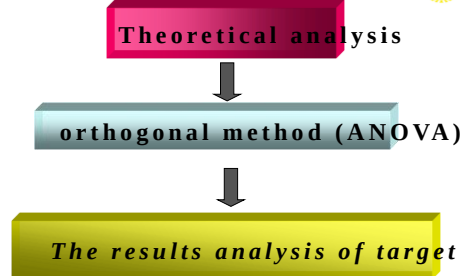
shape memory effect



(a) Austenite (b) Twinned Martensite

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Framework



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Constitutive Equations

$$\dot{\sigma} = \frac{\partial \sigma}{\partial \varepsilon} \dot{\varepsilon} + \frac{\partial \sigma}{\partial T} \dot{T} + \frac{\partial \sigma}{\partial \xi} \dot{\xi} = D(\xi) \dot{\varepsilon} + \Theta \dot{T} + \Omega(\xi) \dot{\xi}$$

- σ 、 ε : stress、strain (pre-strain)
- T : temperature
- ξ : martensite fraction
- $D(\xi)$: Young's modulus,
- Θ : thermo-elastic tensor,
- $\Omega(\xi)$: transformation tensor

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Constitutive Equations

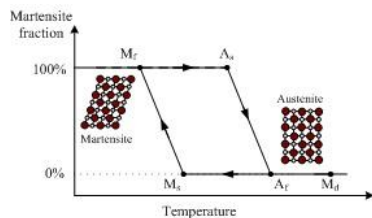
$$D(\xi) = D_a + \xi(D_m - D_a)$$

$$\Omega(\xi) = -\varepsilon_L D(\xi)$$

- D_m : 100% martensite of SMA
- D_a : 100% austenite of SMA
- ε_L : the recovery strain limit

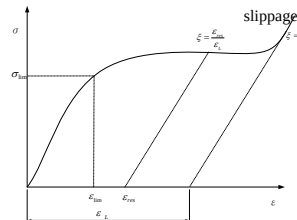
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the recovery strain limit



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the recovery strain limit



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Energy Absorption

Tensile energy

- Finite deflection theory
- the principle of minimum potential energy

$$E_t = \frac{1}{2} \int_0^L \int_0^b \left\{ A_{11} \left(\frac{\partial w}{\partial x} \right)^2 + A_{22} \left(\frac{\partial w}{\partial y} \right)^2 + (2A_{12} + 4A_{66}) \left(\frac{\partial w}{\partial x} \right) \left(\frac{\partial w}{\partial y} \right) \right\} dx dy$$

Where A_{ij} is the tensile stiffness.

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Numerical Example

control factor	Level		
	I	II	III
A: temperature(°C)	50	55	60
B: prestrain(%)	1	3	6
C: volume fraction (%)	60	70	75

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Numerical Example

Results layout using an L27 orthogonal array

run	temperature (A)	prestrain (B)	volume fraction (C)	Energy	S/N ratio (dB)
1	1	1	1	351.62	50.92
2	1	1	2	365.65	51.26
3	1	1	3	373.28	51.44
4	1	2	1	356.58	51.04
5	1	2	2	371.45	51.40
6	1	2	3	379.50	51.58
7	1	3	1	363.07	51.20
8	1	3	2	379.04	51.57
9	1	3	3	387.63	51.77

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Numerical Example

Results layout using an L27 orthogonal array

run	temperature (A)	prestrain (B)	volume fraction (C)	Energy	S/N ratio (dB)
19	3	1	1	374.77	51.48
20	3	1	2	392.74	51.88
21	3	1	3	402.33	52.09
22	3	2	1	380.04	51.60
23	3	2	2	398.92	52.02
24	3	2	3	408.96	52.23
25	3	3	1	386.67	51.75
26	3	3	2	406.70	52.19
27	3	3	3	417.31	52.41

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Energy Absorption

Tensile energy

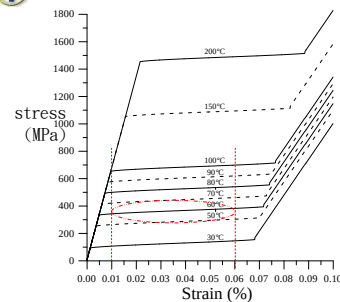
- Finite deflection theory
- the principle of minimum potential energy

$$E_t = \frac{1}{2} \int_0^L \int_0^b \left\{ A_{11} \left(\frac{\partial w}{\partial x} \right)^2 + A_{22} \left(\frac{\partial w}{\partial y} \right)^2 + (2A_{12} + 4A_{66}) \left(\frac{\partial w}{\partial x} \right) \left(\frac{\partial w}{\partial y} \right) \right\} dx dy$$

Where A_{ij} is the tensile stiffness

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The stress-strain relation of SMA



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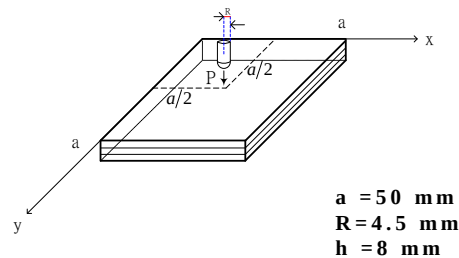
Numerical Example

Results layout using an L27 orthogonal array

run	temperature (A)	prestrain (B)	volume fraction (C)	Energy	S/N ratio
10	2	1	1	363.11	51.20
11	2	1	2	379.10	51.58
12	2	1	3	387.69	51.77
13	2	2	1	368.23	51.32
14	2	2	2	385.08	51.71
15	2	2	3	394.11	51.91
16	2	3	1	374.78	51.48
17	2	3	2	392.76	51.88
18	2	3	3	402.35	52.09

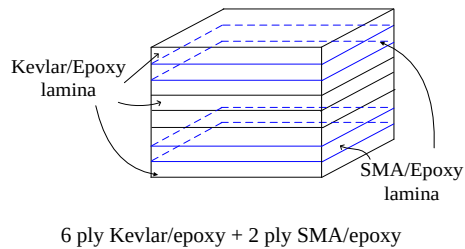
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Geometry



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Hybrid Composite Plates



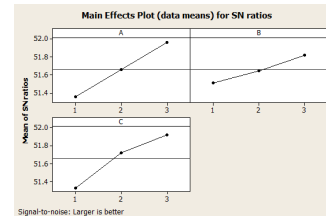
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Results and Discussion

- Effect of control factors on energy absorption of hybrid composites
- A3, B3 and C3 gives maximum energy absorption.

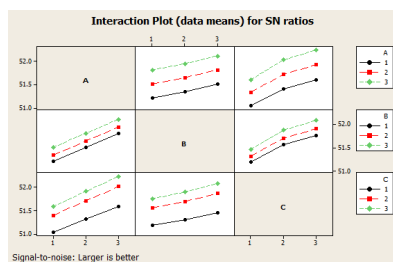


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Results and Discussion



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Results and Discussion

the results of the ANOVA with the energy absorption

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	Contribution
A	2	1.6489	29.250	0.8243	527.20	0.300	44.63
B	2	0.4114	95.060	0.2057	3810.50	0.00	11.13
C	2	1.6253	074.70	0.8127	5054.04	0.00	43.99
AB	4	0.0001	161.65	0.0000	0.32	0.85	0.00
AC	4	0.0072	170.84	0.0018	33.34	0.00	0.19
BC	4	0.0011	86.88	0.0004	8.29	0.00	0.04
error	8	4.3200	30.855	4.006			0.03
Total	126	3.6947	749.37				100

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Conclusions

- Temperature and volume fraction of SMA can effectively improve energy absorption
- Pre-strain effect is low, because of slippage of Ti and Ni atoms in the transformation phase

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Conclusions

- Temperature and volume fraction (AC) interaction have little contribution because temperature chosen in this study was above A_s point, leading to a stable fraction

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附件二：會中參與交流研討之相關照片



