行政院國家科學委員會補助專題研究計畫成果報告

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※高性能材料之銲接與修補製程最佳化研究之總計畫(Ⅱ)※
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計畫類別：□個別型計畫　　■整合型計畫
計畫編號：NSC 90－2216－E－009－029
執行期間：90 年 08 月 01 日至 91 年 07 月 31 日

總計畫主持人：周長彬 教授
子計畫一　：周長彬 教授
子計畫二　：王星豪 教授
子計畫三　：林義成 教授
子計畫四　：周　明 教授
參與人員　：林后堯
蔡曜隆

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□赴國外出差或研習心得報告一份
□赴大陸地區出差或研習心得報告一份
□出席國際學術會議心得報告及發表之論文各一份
□國際合作研究計畫國外研究報告書一份

執行單位：國立交通大學機械工程學系

中 華 民 國 91 年 10 月 30 日

高性能材料之銲接與修補製程最佳化研究(Ⅱ)之總計畫
The Optimum Study of Welding and Repairing Processingof High-Performance Materials

計畫編號：NSC 90-2216-E-009-030
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總計畫主持人：周長彬 教授 國立交通大學機械工程學系
子計畫一：周長彬 教授 國立交通大學機械工程學系
子計畫二：王星豪 教授 國立台灣海洋大學機械與輪機工程學系
子計畫三：林義成 教授 國立彰化師範大學機電工程學系
子計畫四：周　明 教授 國立台灣師範大學工業教育學系
參與人員：林后堯 蔡曜隆 國立交通大學機械工程學系

一、中文摘要

本整合型計畫主要在研究銲接與修補製程參數對材料系統之變形、殘留應力、熱延性、耐腐蝕性、熱裂敏感性、彎曲低週期疲勞、機械性質及微觀組織等之影響。本整合型研究計畫嘗試利用『Model 理論』，輔以電腦運算分析工具來模擬各種材料系統在不同製程參數下之溫度、變形、殘留應力及相變化等相互間的關係。因此，本研究計畫最終目標係以現有且常用的高性能材料之物理特性與機械性質等，以實驗與理論模式來得知各種材料系統之「物理模態」、「力學模式」及「冶金特性」等關係，並配合各種銲接、修補製程與各類的測試實驗，來加以驗證本研究計畫所發展出來的理論模式，以期使『理論研究』與『實際應用』能相互緊密地結合在一起，並藉此推導出有關材料系統與製程參數之相關綜合理論。

1. 銲接與修補最佳化製程研究：本項研究領域包括有：鎳基超合金修補製程參數最佳化研究（由林義成教授主持）。
2. 材料系統之銲接特性分析：本項研究領域包括有：高強度鋁合金銲接熱影響區之特性研究（由周長彬教授主持）、鈦合金銲接構件之彎曲低週期疲勞研究（由王星豪教授主持）。
3. 材料系統之力學行為分析：主要在分析銲接與修補製程對材料系統之變形、殘留應力及彎曲低週期疲勞性等之影響，以作為最佳製程參數、材料冶金結構及製程參數控制系統等的研究依據（由林義成教授與王星豪教授等人負責）。
4. 材料系統之冶金結構分析：主要在分析銲接與修補製程對材料系統之機械性質與微觀組織的影響，以作為最佳製程參數、銲件破損分析及製程參數控制系統等的研究依據（由周長彬教授負責）。

本整合型計畫之第一年各子計畫的研究重點在於探討高性能材料之「物理模態」、「力學模式」及「冶金特性」等相互間的關係，並可初步獲得高性能材料之銲接特性、銲接參數及修補參數等組合關係。其中所採用的材料系統、製程參數及研究方法與步驟等，更可互相分析與比較。

關鍵詞：可銲性、銲補、Gleeble、熱影響區、銲接變形、殘留應力、低週疲勞、鋁合金、超合金、鈦合金

Abstract

The purpose of this research project is to determine the fabrication and repairing weldability of high-performance alloys, includung high-strengthed aluminum alloys, In 718, and titanium alloys. The welding processes included gas tungsten arc welding and plasma arc welding. The Heat Affected Zone simulation was produced by Gleeble machine. Low cycle fatigue test was conducted. The welding distortion and residual stress were measured and compared to the results through finite element simulation. The microstructure of weldment was examined and analyzed by DCS and TEM.

The first year experimental results are presented by the following three sub-project papers.

Keywords: Weldability, Repair Welding, Gleeble, Heat Affected Zone, Welding Distortion, Residual Stress, Low cycle fatigue, Alluninum Alloys, Super Alloys, Titanium Alloys

子計畫一：高強度鋁合金銲接熱影響區之特性研究(Ⅱ)
The Study of Characteristics in Weld Heat Affected Zone of Aluminum Alloys

計畫編號：NSC 90-2216-E-009-030
執行期限：90 年 08 月 01 日至 91 年 07 月 31 日

主持人：周長彬 教授　國立交通大學機械工程學系
計畫參與人員：林后堯 蔡曜隆 國立交通大學機械工程學系

一、中文摘要

本文使用 Gleeble 來模擬 2091 鋁合金銲接熱影響區之顯微組織。經由微差掃描卡計(DSC)，穿透式電子額微鏡(TEM)，拉伸試驗及在 3.5%NaCl 水溶液中進行電化學量測來探討熱影準區之顯微組織，機械性質，腐蝕特性及熱延性。

2091-T3 鋁鋰合金銲接熱影響區強度衰退之原因為可分為兩個區域;在峰值溫度 237℃區域為 GP zones 和部分δ’相之溶解。在峰值溫度為 445"C 區域為δ’相和部分 S’相在加熱過程中溶解，而在冷卻過程中僅少量析出 A 相。熱影響區中擁有最低含量之 GP zones 及δ’相，有最低之孔蝕電位。沿晶剝離腐蝕之主要原因為銲接加熱過程產生 T_2 相，形成於晶界。銲接熱循環之峰值溫度愈高剝離腐蝕愈嚴重。

關鍵詞：鋁合金 2091、銲接熱影響區、銲後熱處理。

Abstract

The microstructures of weld heat affected zone (HAZ)of 2O9l aluminum alloy were simulated by Gleeble .The microstructures，mechanical properties，corrosion charactertics and hot ductility behaviors were investigated by means of differential scanning calorimeter(DSC)，TEM tensile testing and electrochemicaI measurements in 3.5wt.% NaCl solution·

The degradation in strength of weld HAZ of 209l-T3 aluminum-lithium alloy occurred in two regions : ln the region of peak temperature 237℃ was caused by GP zones and partial phase dissolved .In the region of peak temperature 445 ℃ was caused by GP zones，δ’phase and partial S’ phase dissolved during heating process and small amount of δ’ phase precipitate during cooling process . The least amount of GP zones and S’ phase have the lowest pitting potential in weld HAZ .The intergranular exfoliation corrosion was caused by the precipitation of T_2 Phase on grain boundaries . The serious intergranular exfoliation corrosion was observed at higher peak temperature of weld thermal cycle·

Keywords : Aluminum Alloy 2091、Welding Heat Affect Zone、Post Weld Heat Treatment.

行政院國家科學委員會專題研究計畫成果報告

子計畫二：鈦合金銲接構件之彎曲低週疲勞（Ⅱ）

The Study of Fatigue Properties of Ti-alloy Weldment

計畫編號：NSC 89-2216-E-019-007
執行期限：90 年 8 月 1 日至 91 年 7 月 31 日

主持人：王星豪　國立台灣海洋大學機械與輪機工程學系
計畫參與人員：研究生　魏明德　陳律仁
國立台灣海洋大學機械與輪機工程學系

一、中文摘要

本計劃研究方向為二，其一探討三種不同微觀組織的鈦合金，於應用不同應變速率及應變振幅的情況下，其原素材及氬護鎢極電弧銲銲件對低週疲勞性質的比較，實驗結果顯示銲道溶融區硬度由高至低之順序為：Ti-64、Ti-153、CP-Ti。增加應變速率均會使 CP-Ti、Ti-64 和 Ti-153 的拉伸抗拉強度和降伏強度上升，且其伸長量會下降，銲件的趨勢與素材相同，但銲件的強度均較母材低。在疲勞試驗方面，應變速率升高會使 Ti-64 和 Ti-153 疲勞強度上升，高應變振幅呈循環應力軟化，低應變振幅則為循環應力硬化，但 CP-Ti 則顯示相反的趨勢，且 Ti-153 對應變速率的敏感性較 CP-Ti 和 Ti-64 高，CP-Ti 和 Ti-64 銲件主要裂縫大都出現於母材區，其疲勞強度劣於原素材，Ti-153 銲件裂縫位於銲道處，且其銲件疲勞強度優於$\dot{\varepsilon}=5\times 10^{-3}\ s^{-1}$時的素材疲勞強度，但劣於$\dot{\varepsilon}=1\times 10^{-2}\ s^{-1}$時素材疲勞的強度。另一方向著重於四點彎曲低週次疲勞實驗方法開發，探討雙向施加循環應變，模擬構件側向彎曲疲勞特性。

關鍵詞：鈦合金、低週疲勞、應變速率、銲接、四點彎曲疲勞

Abstract

Three different titanium alloys (pure Ti, Ti 64 and Ti153) with different microstructures and their welds were used to study the effect of strain rate and strain amplitude on the properties of low cycle fatigue. It shows that the ultimate tensile strength and the yield strength increase with increasing strain rate but the elongation decreases. Similarly, fatigue strength increases with strain rate. Alloys undergo cyclic strain hardening at the relative small strain amplitude. On the other hand, alloys undergo cyclic strain softening so that stress range decreases with increasing number of strain cycles. The ductile pure Ti and Ti 153 alloy exhibit more sensitive to strain range change than high strength Ti 64. The fatigue strength of Ti 64 welds is inferior to that of parent metal and the failure occurs at the base metal zone. However the fatigue failure of Ti 153 happens at the weld.

Keywords：Titanium Alloys, Strain Rate, Weld, Low Cycle Fatigue

二、緣由與目的

鈦合金具備優異的機械性質、良好的高溫特性、耐腐蝕性及銲接性，而被廣泛應用在工業上。純鈦對化學環境，如氯酸或硫化物等氣氛下，具有很強的抵抗力，故鈍鈦也被應用在石油工業上，如石油精煉廠中之熱交換器，若在純鈦中在入 0.2 % 之鋁則可改善其抗腐蝕特性。商業用之純鈦在強度上，雖較其他鈦合金低，但其抗腐蝕性佳，且價格便宜故其通常應用於強度需求不高的設備上。Ti-6Al-4V 及 Ti-15V-3Sn-3Cr-Al 合金可經由熱處理而得到高強度的特性，而常運用於航太工業上[1-4]。

鈦合金屬於對應變速率具有相當敏感性的結構材料之一，在疲勞試驗中針對 R 值

（Stress Ratio）而言，存在一破裂斷口由劈裂面（Cleavage）至窩穴（Dimple）破壞模式轉換點[5]。於高週次疲勞，結構材料在受反覆負載下，遲滯圈（Hysteresis Loop）中的壓縮應力總是高於拉伸應力，而此現象似乎是鈦合金典型的特徵。Ti-6Al-4V 合金中，β相會受疲勞應變的誘發而形成麻田散體（Deformation-Induced Martensite）的組織[6]。Deimey[7] 指出大氣中的氮、氧、氫若污染鈦合金銲道，則會使銲道延性大幅降低[8]。不同硬度及微觀組織的鈦合金，在不同應變速率及應變振幅的應用下，探討不同微觀組織鈦合金受低週次疲勞性質的影響及其銲件疲勞壽命的比較。

子計畫三：鎳基超合金修補製程參數最佳化研究

A Study on the Optimum Condition During Repairing Process in Ni-base Superalloy

計畫編號:NSC90-2216-E-018-001

執行期限:90 年 8 月 1 日至 91 年 7 月 31 日

主持人:林義成 國立彰化師範大學機電工程學系 教授

中文摘要(關鍵字 ：銲補、電漿銲接、超合金、殘留應力、有限元素)

本研究的目的主要利用電漿銲接研究鎳基超合金修補，並以殘留應力之分析與控制為主。實驗中所採用的銲接方法為電漿銲接，並選用 IN738LC 為母材。並藉由田口方法以銲接走速、電流、預熱溫度、束縛度為參數，以降低銲接殘留應力為目標找出最佳化參數。由於 IN738LC 材料有限，在研究過程中將利用有限元素方法模擬銲接過程之熱應力。其次，利用有限元素方法模擬亦可更廣泛了解銲補參數與熱應力與殘留應力之間相依性．最後由田口方法得知工件固定影響最小，影響最大為預熱溫度，所得最佳水準組合為銲槍走速 3.5mm/s、銲接電流為 40A、預熱溫度為 200℃、工件不用固定，在銲道部份所得殘留應力約為 865MPa 拉伸殘留應力，遠離銲道部份約為-203MPa 壓縮殘留應力。

英文摘要求(Key word：Repair welding , Plasma arc welding , Superalloy , Residual stress , Finite element)

In this study, the repair welding technology of plasma arc welding is used. The finite element method will be used to analyze the thermal and residual stresses during welding process. The welding parameter are welding speed, current, preheat temperature and constraint. We can find the optimum of welding parameter by Taguchi method. An experiment will be done after analyze for identification of analytic results. During welding, the thermal cycle of different locations in weldment will be recorded to compare the temperature field obtained by finite element method.

1. 前言

鎳基超合金因擁良好的抗高溫腐蝕與潛變特性，常被利用於高溫與腐蝕工作環境中，但材料價格十分昂貴，且修補時因熱應力造成熱裂縫和過高殘留應力釋放可能引起之時效應變裂縫[1-3]，在傳統的電弧銲方法中均視其為不可銲補之材料，因此，銲補鎳基超合金之研究十分有意義。然而，隨著電腦速度的提升及硬碟空間的增加，使得有限元素法模擬銲接的過程可行，不僅可以得到殘留應力，亦可以得到銲接過程的熱應力分佈。[4-7]

子計畫四：智慧型電弧銲接線上即時感測/系統辨認與控制系統之研究與發展
A Study on Development of a Automated Monitoring and Controlling System for Arc Welding

執行期限：民國 90 年 8 月 1 日起至民國 91 年 7 月 31 日

計畫編號：NSC90-2216-E-003-001

計畫主持人：周 明
E-Mail:joum@cc.ntnu.edu.tw
執行單位：國立台灣師範大學工業教育學系(所)

Abstract

Arc welding is a complex process, the dynamics of which is affected by many manufacturing conditions, which typically vary during welding or vary from application to application. Further, the modeling of the dynamics and design of the feedback control system require both advanced control theory and deep understanding of welding process principles. It appears that the feedback control system should be designed such that it can tolerate the variations in manufacturing conditions and the resultant process dynamics. This implies that robust control is a potential solution to address the conflict between the increasing demand of quality welds and the limited number of qualified personnel. Hence, this study aims at developing a mathematical frame of robust control of welding processes for welding engineers who understand welding process principles and have elementary feedback control background. The control of the weld geometry is used as an example to demonstrate the details of robust control principle and its implementation.

Keywords：Arc Welding, Weld Geometry, Linear Fractional Uncertainty Model, H-infinity Control System

1. Introduction

Welding is a complex operation. The quality of resultant welds is determined by many welding parameters and manufacturing conditions. If the manufacturing conditions can be exactly controlled, welding parameters which are predetermined based on extensive experiments may be capable of ensuring the weld quality in most applications. However, exact control of the manufacturing conditions is typically very costly and is impractical for most applications. Hence, feedback control appears a practical solution which can adjusts welding parameters to the changed manufacturing conditions to maintain the required weld quality despite the variations in the manufacturing conditions. Unfortunately, feedback control under varied conditions for uncertain process dynamics requires advanced knowledge on process dynamics and control theory for which most manufacturing/welding engineers receive inadequate training. Hence, this paper is devoted to the establishment of a mathematical frame for advanced controls of uncertain welding process dynamics due to uncertain or varying manufacturing conditions. An important control issue, control of weld pool geometry, will be used as example.

To argue the importance of the control of the weld pool geometry, one must realize that all fusion welds involve the melting and subsequent solidification of the base metal. The geometry of the weld bead is a good indicator of the melting/solidifying process. Generally, weld inspection starts by evaluating this weld bead geometry, and is followed by further inspection of the mechanical properties and metallurgical structures. Only those welds that meet the visual inspection criteria will be further checked. Further, weld bead geometry is particularly crucial for sheet metal welding or the critical root pass for multi-pass joints. In the former case, the quality of joints is almost totally dependent on the shape of the weld. In the later case, complete penetration of the root pass is assured by the weld geometry. Thus, the weld geometry is of paramount importance for weld quality control. Of course, to achieve quality welds, the cooling rate must also be controlled.

It should also be pointed out that to obtain practical weld quality control systems, researchers have developed a number of methods and systems to measure the weld geometry. For example, a direct method has been developed to measure the depth of weld pool by detecting solid-liquid interface using ultrasonic reflection techniques [1-4]. Acoustic emission techniques are also used for sensing weld depth [5-6]. Though these methods can distinguish between full penetration and partial penetration, their practical applications are restricted because of the contact between the sensors and the workpiece. Other attempts have been made to develop indirect methods to sense weld quality. Techniques have been used to induce an oscillation on the liquid metal of the weld pool and the result oscillation frequency has been measured to predict the diameter of the weld pool [7-10]. However, surface waves can only be correlated to bulk fluid oscillation for full penetration welds [11]. In order to improve the quality of welding, many sensing methods have been developed by observing the phenomenon of the pool surface. Rokhlin and Guu [12-14] employed radiography to measure the surface shape of the weld pool.