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Full length article

A new procedure for refurbishment of power plant Superalloy 617 by pulsed Nd:YAG laser process

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A B S T R A C T

The present study has evaluated the surface rejuvenation of aged Inconel 617 superalloy by both GTAW and pulsed Nd:YAG laser techniques. The gas tungsten arc welding (GTAW) by heat input per unit length [$Q/V_{(J/mm)}$] of 280, 291.67, 309.74 and 225.48 (J/mm), and the pulse Nd:YAG laser process by the 15.71, 19.43 and 22.32 (J/mm), were employed. The Rosenthal equation was used for calculation of mushy zone (MZ) and partially-melted zone (PMZ). Size of MZ and PMZ in GTAW are more than 31 and 6 times than that of formed in pulsed Nd:YAG laser. According to the characterizations, solidification and liquation cracks were observed in these areas produced by GTAW whereas no cracks were identified in laser treated samples. Also, line scan EDS analyses demonstrated the interdendritic chromium and molybdenum segregation, which facilitated formation of hot cracks. With reduction in heat input per unit length, the hardness increased and the size of solidified metal microstructure reduced in pulse Nd:YAG laser. These comparative results showed that pulse Nd:YAG laser can easily be utilized as a new rejuvenation technique for aged Alloy 617 in comparison to the conventional processes due to extremely narrow MZ and HAZ and better surface soundness and mechanical properties.

1. Introduction

Superalloys are classified into three groups including iron-, cobalt- and nickel-based alloys. Superalloys maintain their mechanical properties at high temperature applications where many kinds of steels are susceptible to creep as a result of thermally-activated deformation [1–4].

Inconel 617 (UNS N06617, also referred as Alloy 617), an austenitic Ni–22Cr–2Co–9Mo alloy, is a solid-solution strengthened superalloy with a special combination of high temperature strength and oxidation resistance. The alloy also has high resistance against corrosive environments and is easily formed and welded by the conventional techniques [5]. Superalloy Inconel 617 is one of the candidate materials for some of the most ambitious EU and US projects for the future generations of power plants and nuclear reactors that has been developed for very high temperature applications in excess of 800 °C [5,6].

In many investigations it has reported that the Alloy 617 may experience remarkable changes in its microstructure and consequently mechanical properties due to subjecting into the high temperature corrosive environment. Formation of oxide layers such as Cr_2O_3, NiO_x, and TiO_2 are observed on the surface of Alloy 617 during elevated temperature operation [7–9]. Further, formation of $Cr_{23}C_6$, $\gamma'(Ni_3(Ti,Al))$, TiN and TiC precipitates at the grain boundaries or in the interior of grains has been demonstrated by the previous works [10–14]. In addition, some grain growth and creep and fatigue cracks are seen in the studies. Other results indicate that the Inconel 617 may experience considerable alterations in the mechanical properties at high temperatures [15–18].

On the other hand, due to high expense of superalloys it is attempted to recover and/or repair the aged and damaged Alloy 617 parts. A study is performed using heat treatment in order to evaluate mechanical and electrochemical properties of Inconel alloy 617 after refurbishment through heat treatment, which presents interesting results on improvement of said properties [19]. However, such procedure may not be used for large scale component such as hot gas

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Table 1
The nominal composition of the base metal (aged Inconel 617) (wt%).

element	Ni	Cr	Co	Mo	Ti	C	Al	Mn	Si	W	Fe	Cu
percent	Base	21.68	11.79	8.55	0.301	0.0728	1.02	0.0389	0.0924	0.169	2.07	0.055

Table 2
Welding parameters of GTAW for surface rejuvenation of aged Inconel 617.

Welding process	Sample	Voltage (V)	Current (A)	Welding speed V (mm/s)	Heat input Q (J/s)	Heat input per unit length Q/V (J/mm)
GTAW	a	10	80	2	560	280
	b	10	100	2.26	700	309.74
	c	10	120	2.58	840	325.58
	d	10	150	3.6	1050	291.67

Table 3
Welding parameters of pulsed Nd:YAG for surface rejuvenation of aged Inconel 617.

	Sample	Frequency (HZ)	Pulse Width (ms)	Welding speed V (mm/s)	Heat input Q (J/s)	Heat input per unit length Q/V (J/mm)
Pulsed Nd:YAG laser	a	10	3	2.8	44	15.71
	b	10	3	2.8	54.4	19.43
	c	10	3	2.8	62.5	22.32

inner casing in the gas turbine indicating need for suggestion an alternative solution. Also, the microstructure evolution during transient liquid phase bonding of alloy 617 is investigated, which proposes a technique for joining alloy 617 [20]. The repair welding by conventional processes and high temperature solution anneal heat treatment are suggested for modification of microstructure and mechanical properties of such alloys [21,22]. Unfortunately, such techniques produce significant costs, and in some cases the repair operations are inherently impossible due to high heat input, severe grain growth or limitation of size of the parts. Moreover, a direct research on refurbishment of aged Alloy 617 is not released.

Recently, the lasers are used as material processing and fabrication of high performance alloys. The lasers are known as low heat input and

Table 4
Required Thermal properties for Inconel 617 from reference [1].

parameters	Inconel 617
T_0	GTAW=300 °C Laser=70 °C
T_L liquidus temperature	1380 °C
T_S solidus temperature	1330 °C
α	$3.85*10^{-6}$ (m^2/s)
k	13.5 (J/ms °C)

Table 5
The results of the calculation of PMZ width, with $Q/V_{(J/mm)}$, a) 280, b) 309.74, c) 325.58, d) 291.67 of the GTAW and a) 15.71, b) 19.43, c) 22.32 of the pulsed Nd:YAG laser.

Welding process	Sample	Z_1, Weld center distance to liquidus temperature (mm)	Z_2, Weld center distance to solidus temperature (mm)	$Z_2 - Z_1$ or PMZ width (µm)
GTAW	a	2.88	2.97	90
	b	3.09	3.17	80
	c	3.16	3.24	80
	d	2.91	2.98	70
Pulsed Nd:YAG laser	a	0.35	0.36	10
	b	0.42	0.434	14
	c	0.47	0.49	20

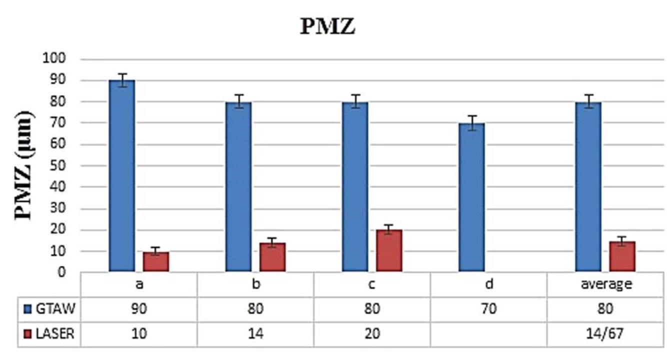

Fig. 2. Results showing the calculation of PMZ width, with $Q/V_{(J/mm)}$, a) 280, b) 309.74, c) 325.58, d) 291.67 of the GTAW, and a) 15.71, b) 19.43, c) 22.32 of the pulsed Nd:YAG laser.

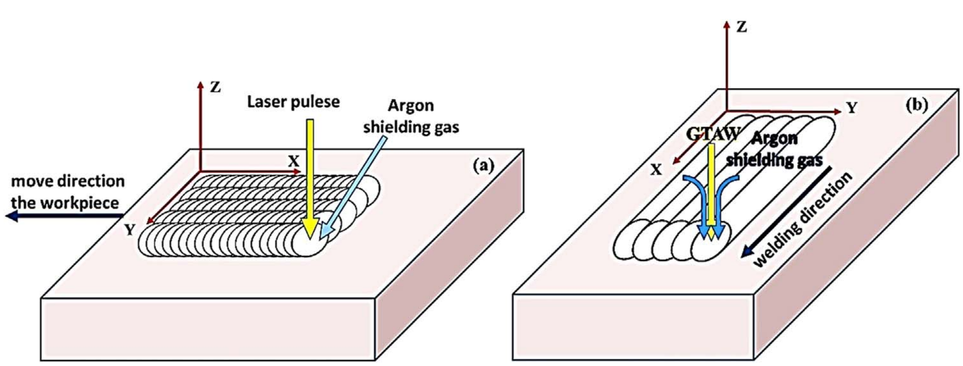

Fig. 1. Schematic of the welding process and modeling: (a) pulse Nd:YAG laser, (b) GTAW, and (c) boundary conditions of modeling.