THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
Three Park Avenue, New York, N.Y. 10016-5990

99-GT-313

BREAK

A STUDY ON FUSION REPAIR PROCESS FOR A PRECIPITATION HARDENED IN738 Ni-BASED SUPERALLOY

Dae-Young Kim, Jong-Hyun Hwang, Kwang-Soo Kim and Joong-Geun Youn
Hyundai Industrial Research Inst., Hyundai Heavy Industries Co., Ltd.
1 Cheonha-dong Dong-ku Ulsan Korea 682-792

Presented at the International Gas Turbine & Aeroengine Congress & Exhibition
Indianapolis, Indiana — June 7–June 10, 1999
This paper has been accepted for publication in the Transactions of the ASME
Discussion of it will be accepted at ASME Headquarters until September 30, 1999

ABSTRACT

Several fusion repair processes such as laser cladding, laser welding and gas tungsten arc welding have been taken into consideration for repairing IN738 precipitation hardened Ni-based superalloy material. Effect of heat input on weld cracking susceptibility has been studied to obtain optimum condition for crack free welds. Variations in cracking susceptibility as a function of welding heat input is discussed with reference to metallurgical characteristics of the welds.

1. INTRODUCTION

Turbine blades in land based power generating combustion turbines burning low grade fuels frequently suffer from premature failures such as airfoil tip loss due to hot corrosion and low cycle fatigue cracking. Refurbishment of the damaged turbine airfoil is commonly implemented due to its low cost as compared to replacement by new parts. Several repair processes such as welding, brazing and spray deposition have been introduced and are well-established for actual commercial repair applications(Dodgson, 1982). Among these repair processes fusion welding process is very competitive one due to a relatively low initial investment. It is, however, well known that high strength precipitation hardened nickel based superalloys possess poor weldability, for example cracking in the weldment during welding and post weld heat treatment(Liburdi and Lowden, 1985). This cracking tendency is known to increase with an increase in aluminum and titanium content, which are γ' precipitate former. Specialized techniques such as high temperature preheating and employment of lower strength filler metals have been tried to prevent such cracking problems(Jahnke, 1982). These difficulties in controlling weld cracking have resulted in repair limitations to the hot gas path components, especially turbine blades. If it is possible to enhance repair area for the high strength precipitation hardened nickel based superalloy, it will contribute substantially to the reduction of life cycle cost of the combustion turbine.

Effect of welding heat input on cracking sensitivity of the IN738, a precipitation hardened nickel base superalloy, using gas tungsten arc(GTA) welding and laser welding has been studied to obtain optimum condition for crack free welds of IN738 alloy. Optimization of laser cladding process for IN738 alloy was also conducted to look into the possibility of introducing it as an alternative process for replacing preheating arc welding process for the alloy.

2. EXPERIMENTAL PROCEDURE

Bead-on-plate welded specimens were made using cast IN738 plate and filler metal alloy. Each plate specimen was 25mm X 200mm X 5mm in size. Chemical compositions of IN738 base metal and IN738 filler metal powder used for laser cladding studies are shown in Table 1. Gas tungsten arc welding(GTAW) conditions and laser welding(LW) conditions are summarized in Table 2 and Table 3 respectively. Dye penetrant inspection was conducted to evaluate the propensity of cracking after welding. Microstructural evaluation and hardness tests were also conducted to quantify the differences in cracking susceptibility of IN738 welds as a function of welding heat input.

Table 1. Chemical compositions of IN738 base metal and filler metal powder

Descriptions	Chemical Composition, wt.%							
	Ni	Cr	Co	Al	Ti	W	Mo	Ta
Cast IN738	Bal.	15.9	8.34	3.42	3.32	2.76	1.68	1.76
IN738 Filler Metal Powder	Bal.	15.9	8.34	3.25	3.37	2.77	1.76	0.83

Table 2. Process variables of gas tungsten arc welding employed in this study

Descriptions	Process Variables			Heat Input*1), kJ/cm
	Current, A	Voltage, V	Speed, mm/min	
GTAW-5.5	138	12	180	5.5
GTAW-7.5			130	7.6
GTAW-9.5			100	9.9

*1) Heat Input(kJ/cm) = (Current(A) X Voltage(V) X 60 X 10) / (Speed(mm/min.) X 1000)

Table 3. Process variables of laser welding employed in this study

Descriptions	Process Variables			Heat Input*1), kJ/cm
	Power, kW	Working Distance, mm	Speed, mm/min	
LW-2.0	2.0	220	600	2.0
LW-4.0			300	4.0
LW-6.0			200	6.0
LW-8.0			150	8.0

*1) Heat Input(kJ/cm) = (Power(kW) X 60 X 10) / Speed(mm/min.)

3. RESULTS AND DISCUSSIONS

Effect of Welding Heat Input - Gas Tungsten Arc Welding

Cracking rate of the autogenous GTA welds in IN738 alloy decreased as the heat input decreased from 9.9 to 5.5kJ/cm as shown in Fig. 1. The data suggest a heat input under 5.5kJ/cm is required for producing crack-free welds. Cracks were observed both at the fusion line and at the weld metal itself along dendrite boundaries as shown in Fig. 2. Fig. 3 showed the effect of heat input on the solidification microstructure of the IN738 GTA weld. As heat input increased, morphologies of the weld metal changed from fine columnar to coarse cellular shape. Dendrite arm spacing decreased as welding heat input decreased as shown in Fig. 4. It could be concluded that finer dendrite microstructure could reduce cracking susceptibility of the IN738 weldment by decreasing effective stress acting along the dendrite boundaries.

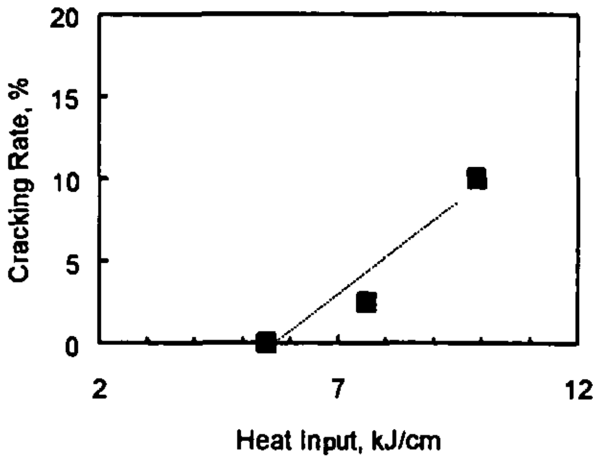

Fig. 1 Cracking rate in IN738 GTA weldment as a function of welding heat input (Cracking Rate = (Crack Length / Total Weld Length) X 100, %)

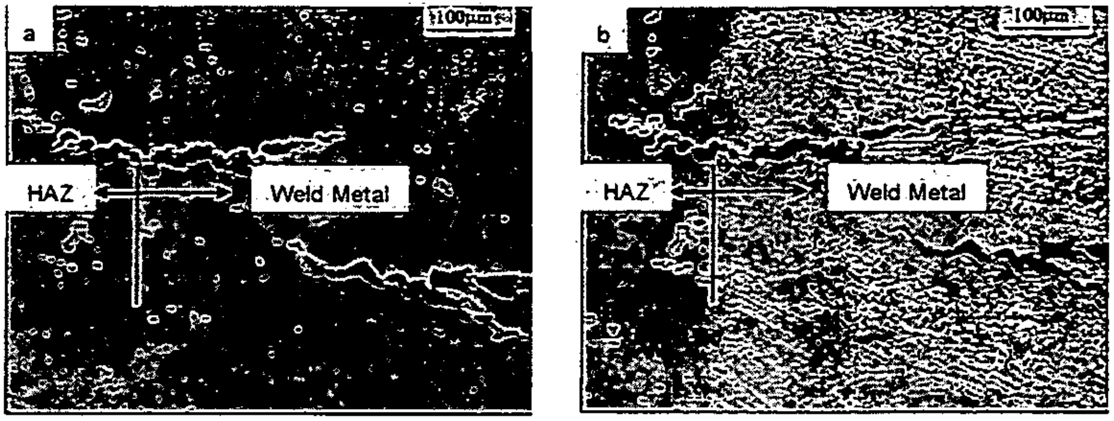

Fig. 2 Features of cracks observed in the IN738 GTA weldment ; (a) before and (b) after etching

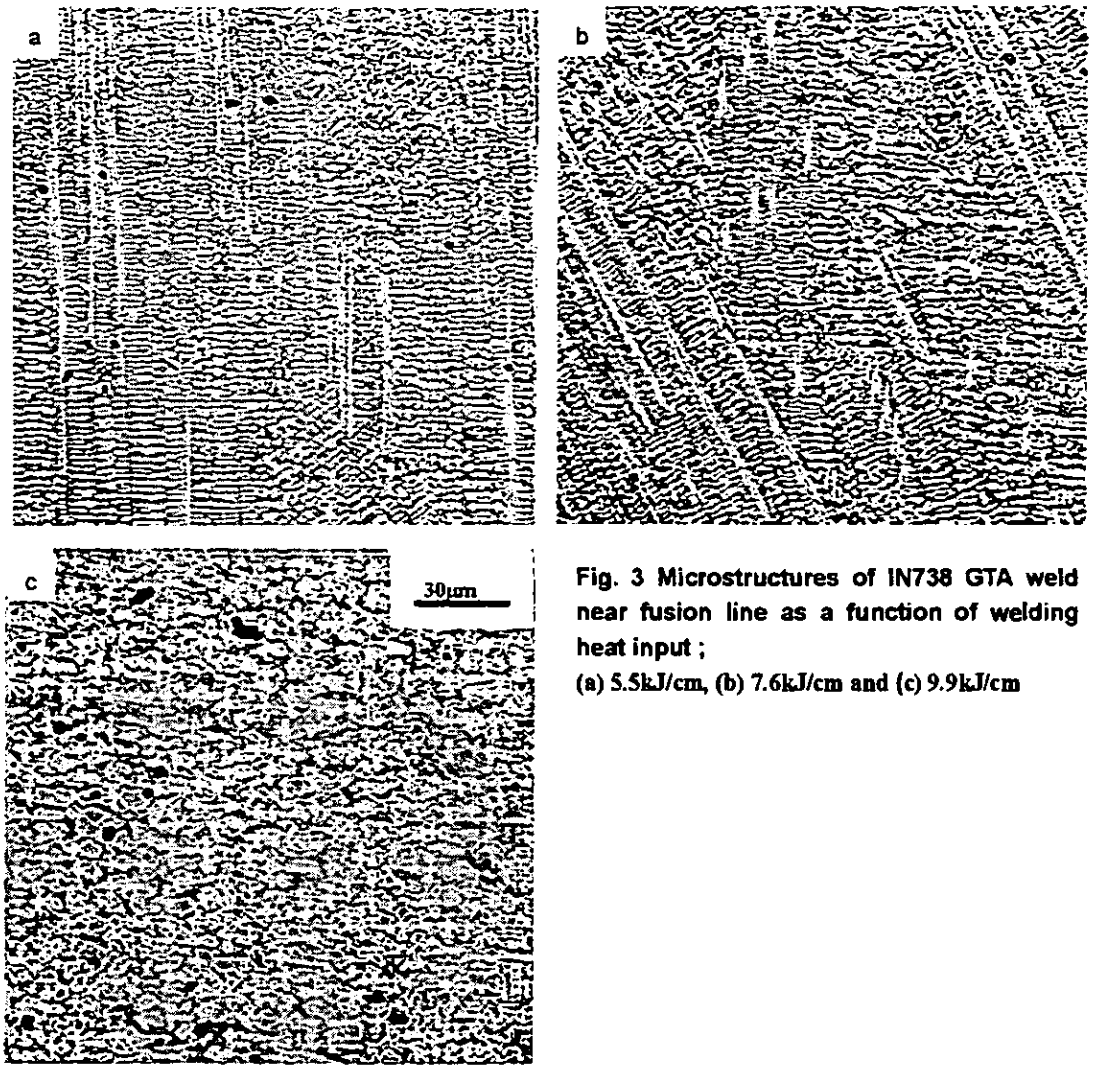

Fig. 3 Microstructures of IN738 GTA weld near fusion line as a function of welding heat input ;

(a) 5.5kJ/cm, (b) 7.6kJ/cm and (c) 9.9kJ/cm

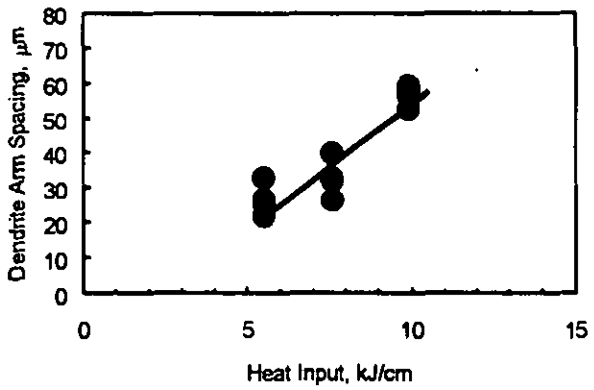

Fig. 4 Dendrite arm spacing in IN738 GTA weld as a function of welding heat input

Effect of Welding Heat Input – Laser Welding

No crack was observed in the autogenous laser weldment of IN738 alloy in the heat input range of 2 to 8kJ/cm. Microstructure of the weld reveals finer dendrite microstructure, compared with the GTA weld, Fig. 5. The dendrite arm spacings shown in Fig.6 lie in the range of 6 to10μm indicating much finer spacing than that observed in GTA weld(20 to 50μm). These finer microstructures in the weld metal lead to an improvement in the cracking resistance of IN738 laser weldment. Laser weldment showed HAZ softening depending on the heat input applied as shown in hardness distribution in Fig. 7. Even though this HAZ softening behavior impairs the HAZ cracking resistance of the precipitation hardened nickel based superalloy(Haafkens and Matthey, 1982), this study show that it is possible to obtain crack free weldment by laser welding due to'a finer weld microstructure. This indicates that laser welding of IN738 alloy enhances applicable heat input range without any cracking problems due to a relatively faster cooling rate than the GTA welding

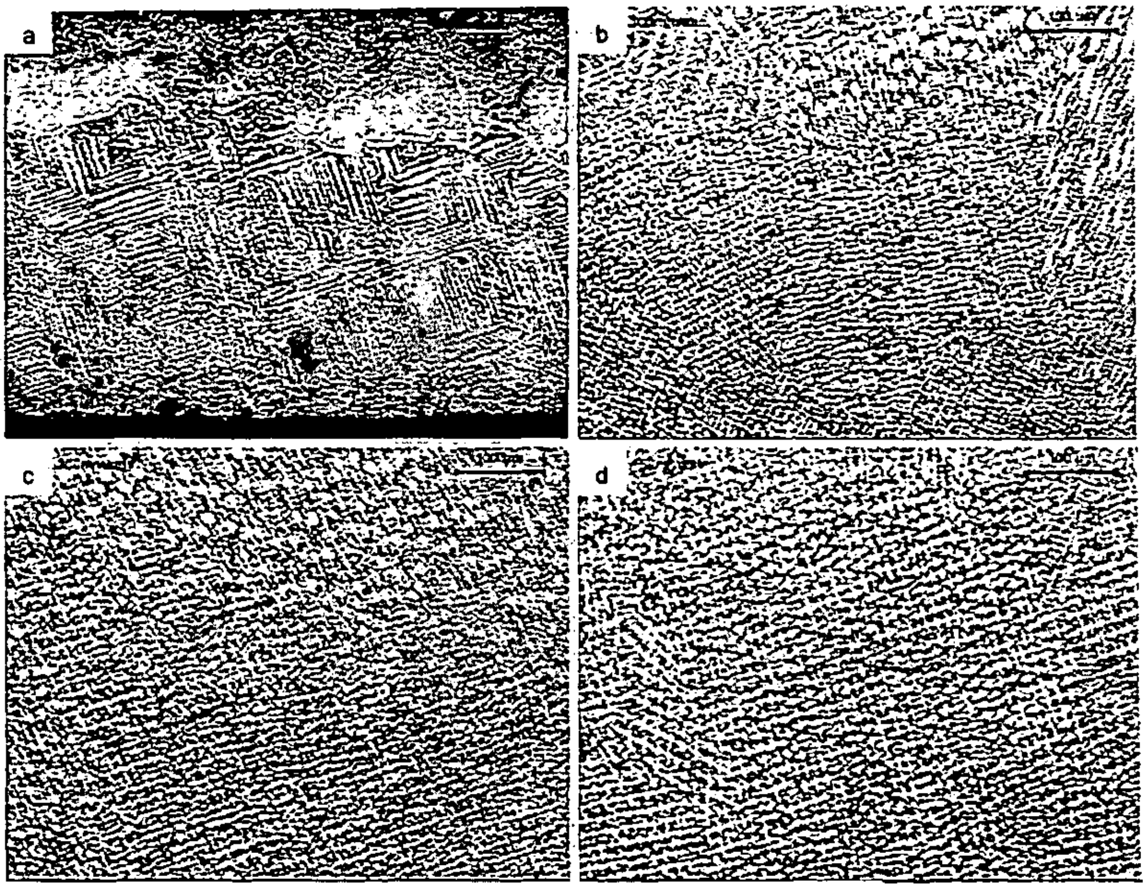

Fig. 5 Microstructures of IN738 laser weld near fusion line as function of welding heat input ;
(a) 2kJ/cm, (b) 4kJ/cm, (c) 6kJ/cm and (d) 8kJ/cm.

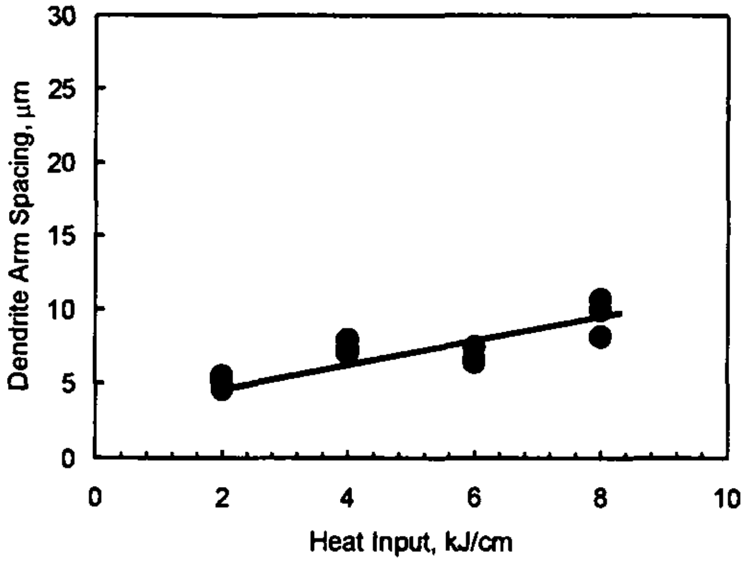

Fig. 6 Dendrite arm spacing in IN738 laser weld as a function of welding heat input

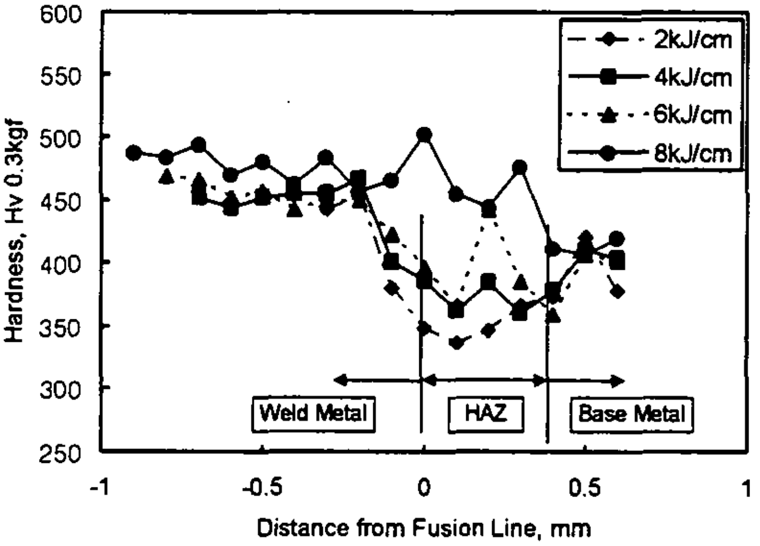

Fig. 7 Hardness distribution in laser weldment as a function of welding heat input

Laser Cladding

Laser cladding of the IN738 alloy using matching IN738 powder filler metal was conducted. There was no occurrence of weld cracking in the as-welded condition as shown in cross sectional microstructure of Fig. 8. Based on this study, laser cladding can also be used as an alternative fusion process to conventional GTA welding. Hardness distribution of the laser clad layer also indicated the softening behavior in heat affected zone as shown in Fig. 9.

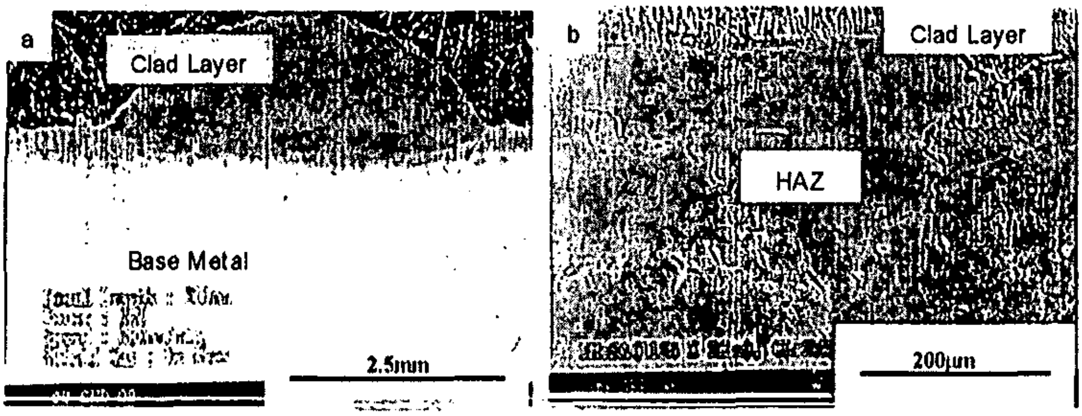

Fig. 8 Cross-sectional microstructures of laser clad layer ;
a) lower magnification, b) higher magnification

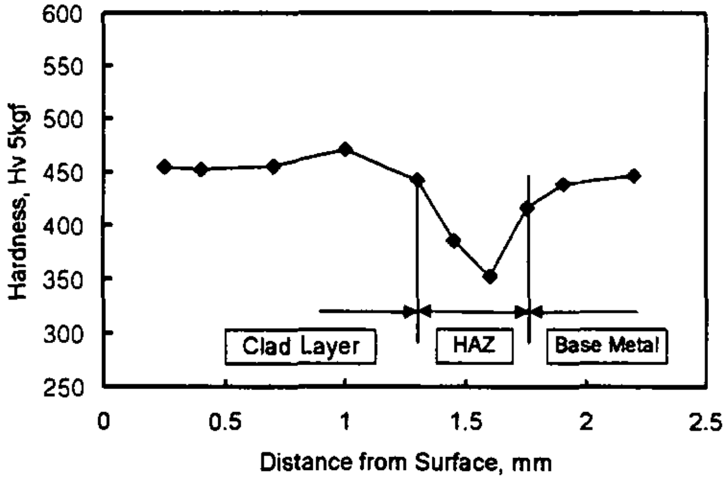

Fig. 9 Hardness distribution in the laser cladding layer

4. CONCLUSIONS

Following conclusions could be drawn from this study with regard to the effect of welding heat input on cracking susceptibility in IN738 weldments.

1) The lower heat input in GTA welding of IN738 alloy results in crack-free weldments by forming fine dendrite microstructure.

2) Laser welding of IN738 alloy enhances applicable heat input range without any cracking problems due to a relatively faster cooling rate than the GTA welding.

3) Laser cladding process can be chosen as an alternative repair process to GTA welding with high temperature preheating.

REFERENCES

1. Dodgson, J. S., 1982, "Repair Techniques for Hot Gas Path Components in Industrial Gas Turbine", ASME Paper No. 82-GT-104.
2. Liburdi, J. and Lowden, P., 1985, "Repair Techniques for Gas Turbine Components", AGARD Conf. Proc. No. 398, Sept., 22-1.
3. Koren, A. et. al., 1982, "Improving the Weldability of Ni-Base Superalloy 713C", Welding J., Vol.61, No.11 348-s.
4. Jahnke, B., 1982, "High-Temperature Electron Beam Welding of the Nickel-Base Superalloy IN-738LC", Welding J., Vol.61, No.11, 343-s.
5. Haafkens, M.H. and Matthey, J. H. G., 1982, "A New Approach to the Weldability of Nickel-Base As-Cast and Power Metallurgy Superalloys", Welding J., Vol.61, No.11, 25.