High Density Energy Welding of Gas Turbine Alloys

Hwan Tae Kim
Korea Institute of Machinery & Materials,
e-mail : htkimm@hanmail.net

요약 항공기의 제트 엔진을 비롯하여 육상용 발전기, 선박용 엔진, 로켓 엔진 등에 널리 사용되는 터빈 블레이드를 포함한 고온용 가스터빈 부품은 최대 온도 1200℃ 이상의 고온에 노출되어 가혹한 기계적 응력을 받는 동시에 고온에서의 표면 안정성이 요구되므로 초내열 니켈 합금(superalloy), 티타늄 합금, 내열강 등의 고온강도가 우수한 합금이 사용된다. 그런데 합금성분이 많이 첨가된 내열 합금을 용접하는 경우, 미세균열, 용접부의 기계적 성질의 저하, 용접열영향부의 내식성과 내산화성의 저하, 용접외부 결함에 의한 피로강도 저하 등의 문제가 발생하므로 이를 해결해야 한다. 본고에서는 생산성과 용접품질이 우수한 고밀도 에너지빔 용접의 적용 현황에 관하여 고찰코자 한다.

1. Introduction

The increasing features of great power, reduced weight, lower cost and the requirement for higher yields and more automated production systems to the modern gas turbine alloys is placing stringent demands on the manufacturing techniques and performance requirements of the materials, and the manufacture employs a wide range of high temperature alloys that demand the use of high quality and efficiency welding processes to produce welds. This has led to an increasing interest in the use of high density energy beam welding technologies for joining the assemblies with particular interest of the ability to apply controlled heating in precise areas, low heat inputs, low distortion joints and the ability to operate at high production rates in a flexible manner. The laser beam welding process has the advantage of being able to operate in any desired atmosphere than the electron beam welding. ND:YAG laser can weld relatively thin materials, and typical welding parameter are long pulse widths, high Joules, and in the case of seam welding, high pulse rates.

2. Joining of high temperature Titanium alloys

Ti alloys which have high strength to weight ratio are essential materials in the development of present and future gas turbine system. The welding of Ti alloy needs particular precautionary measure because Ti-base alloys have a very high chemical affinity for most of the air elements like O_2 and H_2 which embrittle the welds. Further, grain growth during the welding needs to be minimized for maintaining its toughness characteristics.[1] Ti-6Al-4V alloy has poor weldability, and though the as welded strength is invariably greater than that of the base material, the weldment ductilities are very low. The poor as welded ductility is attributed to a large prior β grain size and an acicular martensitic microstructure. A lower energy input reduces β grain size, but also increases the cooling rate and promotes a more needle-like martensitic strecture. The laser beam welding of Ti-6Al-4V alloy shows more uniform welds than electron beam weld bead. S.L. Gobbi carried out on Ti6Al4V and Ti6Al2Sn4Zr2Mo sheet using a CO_2 laser and ND:YAG laser and found that high power pulsed ND:YAG laser welding produces the autogeneous butt welds with full penetration and regular bead profile.[2] The undercut and slump could be controlled by pulse energy, pulse duration, frequency, waveform and overlapping rate. The results of the weldability are summarized in Table 1. Beta-21S is superior oxidation resistance and mechanical properties at elevated temperature (nominal composition:

Ti-15Mo-2.7Nb-3Al-0.2Si) which exhibits nearly equiaxed and recrystallized β grains, and Beta-C^{TM} is a metastable-beta Ti alloy (nominal composition: Ti-3Al-8V-6Cr-4Mo-4Zr) which can be thermo-mechanically processed and heat treated to provide excellent combinations of strength, ductility, and fracture toughness. CO_2 laser beam welding is effective in producing fine-grained welds between Ti-6Al-4V and Beta-C sheet. Macrosegregation within the fusion zone resulting from transverse-solute banding during solidification affected the tendency for local martensitic transformation of β phase to α'' (orthorhombic) in the fusion zoon on cooling. Postweld aging results in α precipitation within the retained β phase and tempering of the martensite to extremely $\alpha + \beta$ phase. The aging temperature to 593 ℃ exhibited a strength superior to the base metals and acceptable ductility.

3. Joining of high temperature Ni-base superalloys

Ni-base superalloys are strengthened by a large volume fraction of stable precipitations. These are taken into solid solution within the HAZ associated with the welding process and rapidly reprecipitate during cooling, imparting very high strength to the metal. The problem of cracking becomes more severe for high heat input welding process because greater accomodation is required. It follows that such Ni-base superalloy may exhibit greater weldability with a low heat input process, with a limited HAZ. The Lumonics tested the C263 alloy from 0.9 to 3.0 mm in thickness, where the fibres from the 3 ND:YAG lasers were brought together in a common output housing (multilase type).(3) It is noted that highest welding speeds were achieved when using the Multilase type output housing with 1.5 mm spot size and hence longer focal length and longer depth of focus. The weld width has decreased almost inversely propertional to the increase in welding speed for this C263 alloy. The sound laser welds in this C263 alloy exhibited tensile strength equal to the parent metal and Table 2 shows the fatigue properties of the laser beam weldment similiar to those achived by electron beam welding. Inconel 718 comprises precipitation- hardened Ni bases. The presence of niobium, however, sensities the Inconel 718 to intergranular liquation, particularly with electron beam welding.(4) This alloy is more sensitive to solidification cracking in the aged state than in the solution treated state. The advantage of the ND:YAG laser process is that it leads to shapes equivalent to those obtained by electron beam (with a nail head which is very marked in the pseudo-pulsed mode) while still giving high flexibility for application using fiber optics. Excessive heating of the ODS alloys caused oxide coalescence leading to severe agglomeration of oxides dispersions and disruption of elongated grain structure such that the dispersoid is no longer effective in pinning the dislocation. Laser beam welding reduced the hardness due to the absence of gamma prime phase in the weld metal. Ni-base IN 738 superalloy has been laser beam welding tested, after a heat solution treatment at 1120 ℃ for 2 hours in vacuum chamber.(5) The cracks formation is strongly related to the presence of large primary carbides : a medium temperature pre-heating can be convenient when exrensive carbides dissolution is not possible. The time-to-vaporisation behaviour of Nimonic 75 alloy, during the ND:YAG laser beam welding showed that the most efficient heat input technique is an initial high intensity pulse section to raise the surface temperature to vaporisation as fast as possible.(6) It is also possible to control the degree of penetration of a laser pulse by adapting the temporal power of the pulse to the varying heat transfer conditions which will exist during the lifetime of the pulse.

4. Conclusion

Investigation on the feasibility of high density energy beam welding of gas turbine materials has shown that the laser beam processing has great potential application and flexibility for use in the gas turbine manufacturing industry with the advantages of high efficiency of machining of practically high temperature alloy materials, absence of 'cutting forces' during machining of components with low stiffness, no special atmospheres or vacuum required, wide possibilities for automation, versatility of application for dimensional machining and welding, and absesce of harmful ionizing radiation. The laser beam welding of Ti-6Al-4V alloy shows more uniform welds than electron beam weld bead. The laser beam also can be transmitted substantial distances which provides the opportunity for multi-station working, and the development work with multi-process capability system of multi-purpose processing and multi-station processing will address issues which may arise in future high power laser operations: methods of beam delivery over long distance, intergration with machine tools, economical manufacturing of low volume production and system reliability.

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Table 1. The Weldability of the titanium alloys

material	process	weldability
Ti64	2.5 KW CO_2 CW filler wire	satisfactory joints were achived, regarding, both to geometry and porosity
Ti64	2.5 KW CO_2 CW in-corporated filler	the undercut and the porosity can be controlled easily
Ti64	2.5 KW CO_2 CW cosmetic pass	surface was very smooth and bright, and the undercut was eliminated completely
Ti6242	ND:YAG pulse laser	the bead has the regular and smooth profile, without undercut
Ti64	2.5 KW CO_2 CW filler wire	the longitudinal and circumferential beads have no oxides. silver shiny color appear

Table 2. Fatigue strength of C263 Ni-alloy welds (5×10^7 cycle)

process	25 ℃	750 ℃	850 ℃
LBW	167-218 (N/㎟)	237-264 (N/㎟)	56-184 (N/㎟)
EBW	190 (N/㎟)	232-270 (N/㎟)	154-185 (N/㎟)