LASER WELDING OF DISSIMILAR METALS WITH LARGE THICKNESS RATIO

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INTRODUCTION

Steam generators are critical components for the Prototype fast Breeder Reactor being designed at the Indira Gandhi Centre for Atomic Research, Kalpakkam. A leak in the steam generators can have serious consequences leading to rupture of steam generator tubes. Consequently, by introducing a known leak in the experimental loop, data is required to be generated which can predict the response of the material to the leak as a function of leak rate, time, temperature, steam pressure and the size of the microhole as a result of sodium water reaction. It is in this context that development of "Leak Simulators" assumed importance, especially to save foreign exchange. This involves development of microholes in the leak simulator tube and sizing them to known microleak rates. Steam leaking through such a microhole is required to interact with sodium at a given pressure and temperature. A thin foil (about 50 micron thickness) welded around the microhole is designed to contain the steam until the pressure rises to the required value and burst open to permit the steam at 170 bars, 753K to interact with sodium. Consequently, development of welding a 50 micron thin stainless steel 304L foil to a 2.25 Cr-1 Mo steel tube 17.2mm outer diameter and 3mm wall thickness forms an important part of the leak simulator development. Fig. 1 shows the 50 micron thin miniature rupture disc mounted on the "Leak Simulator" steel tube using a lap welded joint. The rupture disc is required to rupture at a pressure of 170 bars at 753K. This paper deals with laser welding of dissimilar metals with large thickness ratio with reference to its application to the welding of stainless steel rupture disc to 2.25 Cr-1Mo steel tube in leak simulators. Lap weld joint configuration is used throughout the development work.

Selection of the Welding Process

A variety of methods to weld a very thin rupture disc to a thick steel base were considered. The constraints in selecting the welding process were not only from metallurgical consideration but also from engineering considerations in view of the requirement of an enormously small size of weld on a miniature rupture disc. While a large thickness ratio coupled with dissimilar materials posed metallurgical problems, handling of extremely thin miniature rupture disc and providing necessary clamping pressure during welding over a small diameter in the range of 6mm to 9mm restricted the choice of the welding process to any one of the four cnadidate welding techniques like laser welding, electron beam welding, micro-plasma welding and resistnace welding.

The resistance welding process offers a number of advantages. It is simple in handling and easily available. Since the top and bottom copper electrodes hold the job and provide the required clamping pressure, the necessity of any special welding fixture does not arise. However, for a large thickness ratio of 60, as in the present case, the thin rupture disc will melt away under the influence of the current, whereas the thik base metal with its large thermal capacity and good conductivity transmits the heat to the immediate neighbourhood and does not easily melt in the local region. A few experiments were conducted to examine the implications and as expected the welds were of very poor quality and the welded disc peeled off with manual force. Hence resistance welding for the intended application was ruled out.

Laser are of special advantahe for this application since the laser beam diameter is very small and can be directed with better precision to the intended location. In the case of welding a rupture disc it is very essential to ensure geometrical reproducibility of the welding diameter. Especially the inner circumference should be free from sharp local vatiations which can adversely influence the reproducibility of the rupture pressure, an essential parameter for the performance of the "Leak Simulators". Both the Electron Beam welding as well as the Laser welding have the distinction of giving a smooth, uniform and a well defined inner circumference of a circular weld joint. However, availability of a suitable laser welding machine was an encouraging factor to adopt this process for the said development work. It may be pertinent to mentioned that, special welding fixtures are required to meet the critical joint set-up called for in laser welding.

First Phase of Development

The development work was carried out using the 600 Watts CO_2 laser equipment available at the Welding Research Institute, BHEL, Tiruchirapalli. Initial trials were conducted to weld 50 micron thin stainless steel foil on 2.25 Cr - 1 Mo steel pads. Table 1 shows the parameters recorded during these trials and the inferences drawn. Operating at 50 to 60 watts power and 70 mA current, the welding speed was varied from 300 to 1000mm per minute during these trials. Most of the trials yielded poor weld joint, while one specimen indicated excess penetration in the range of 300 microns in metallographic examination. Some of these specimens exhibited burn-through. Marked thinning of the rupture disc material adjoining the weld noticed in the metallohraph (Fig. 4) is detrimental to the strength of the joint.

Various parameters like the surface finish, welding speed, focal point position, clamping pressure relative to the weld line, design of fixture, flatness requirements in the fixture's holding surface etc. which are likely to affect the weld joint were carefully observed and analyzed to evaluate the possible causes of the poor weld joints obtained. Corrective actions like improving the design of the fixture, improving surface finish of the weld test pads, moving the clamping line close to the weld line, adjusting

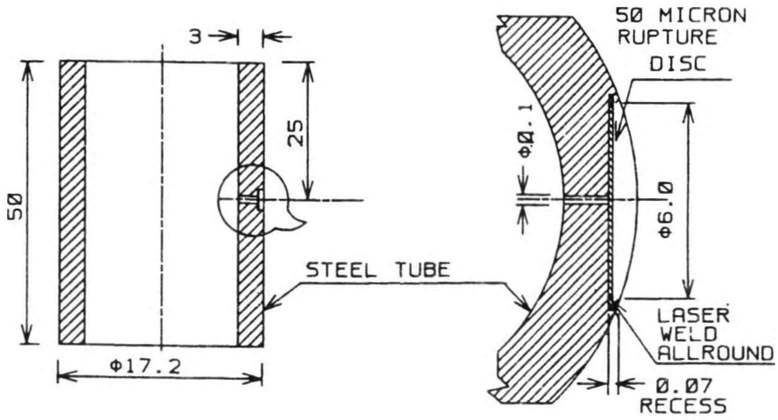


Fig. 1 : Rupture Disc Mounted on Steel Tube

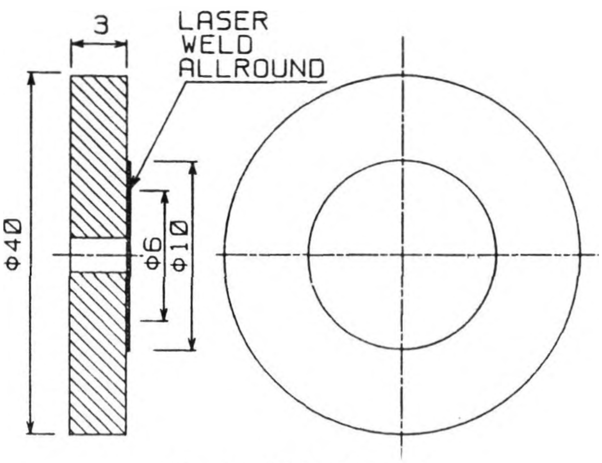


Fig. 2 : Weld Test Pad

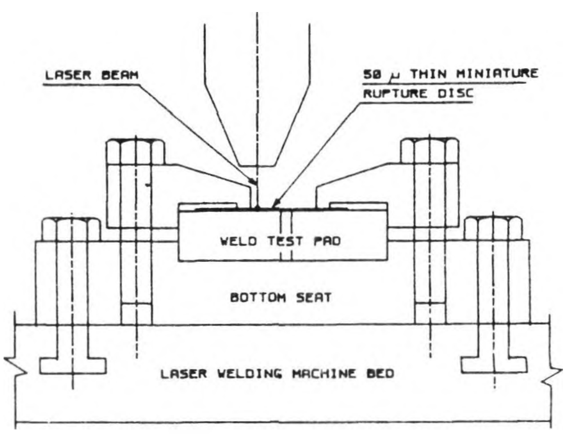


Fig. 3 : Laser Welding Fixture

the local point distance etc. were implemented in the next phase of development work.

Second Phase of Development

Improved laser welding fixtures and weld test pads were employed in this phase of the work and parametric studies were conducted as described below.

Weld Test Pads

Typical laser weld test pad is shown in **Fig. 2.** In order to simulate the real life situation with respect to material combination and the thickness ratio during welding trials, the weld test pad was designed in the same thickness combination and was machined from the 2.25 Cr-1 Mo steel. Flat disc type weld test pads were chosen instead of tubular sections not only to facilitate pressure testing of the weld joint and the rupture disc but also to provide working comfort during development work and the burst tests.

The surface finish of the rupture disc was measured to be 0.2 microns. In the event the mating surface does not have a comparable surfaces of the weld test pads were ground to 0.6 micron surface finish.

Welding Fixture

The welding fixture was suitably designed and fabricated in two parts, viz. bottom seat and top annular clamp (**Fig.3**).

(a) The surface of the bottom seat, which holds the weld test pad is required to be flat and parallel to the surface sitting on the laser welding machine bed, in order to maintian the uniform focal point distance during welding. To achieve this the flatness of the seating surface was specified and achieved within 10 micron per 100 mm length.

(b) The top clamp was designed for effectively clamping the foil on the weld pad and to provide the clamping pressure on 10 mm diameter, annular to the circular weld line. A central cone shape is also provided in the design to accommodate the approaching laser beam nozzle close to the weld joint with an appropriate focal point distance from the foil and also to ensure effective purging of shielding gas.

Parametric Studies

Parametric studies were conducted on a number of weld test pads to optimize the laser welding parameters, including welding speed and focal position. While argon was employed as shielding gas for most of the welding trials, the gas mixture of nitrogen and carbon-dioxide was used in some trials.

Table 2 shows the welding parameters recorded during this phase of work. Visual examination of the weld of the first two specimens indicated cutting through the joint over quarter

Table 1

Sl.No.	Current mA	Power Watts	DIA of Weld mm	Feed Rate mm/min	Focal Position mm	Remarks
1	70	50	6	300	2	HAZ Failure Foil peel test OK
2	70	50	6	300	2.3	Burn through
3	70	50	6	400	2.3	--- do ---
4	70	50	6	1000	2.3	--- do ---
5	70	50	8	300	2.3	--- do ---
6	25	30	6	300	2.3	Unstable plasma No bonding
7	70	60	6	300	2.3	Burn through
8	70	60	6	300	2.3	--- do ---
9	4	60	6	300	2.3	No bonding
10	4	60	6	300	2.3	No bonding

Note : Shielding gas used was Argon at a flow rate of 20lit/min.

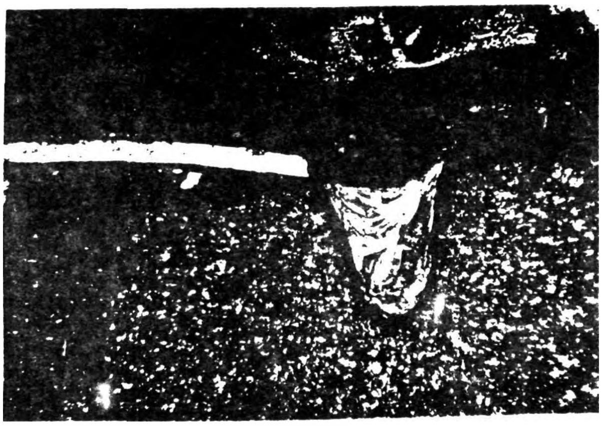
Table 2

Sl.No.	Current mA	Power Watts	DIA of Weld mm	Feed Rate mm/min	Focal Position mm	Remarks
1	70	50	6	1000	2	Fig.5(a) 1/4 cut Foil liftinh
2	70	50	8	1000	2.3	Fig.5(b) 1/4 damagereduced
3	70	50	9	1000	2.3	Fig.5(c) good bead appearance
4.	70	50	9	100	0	Fig.6 less bead width, sputtering
5	70.	50	9	1000	1	--- do ---
6	25	30	9	1000	1.6	--- do ---
7	70	60	9	1000	3	unstable plasma intermittent welding
8	70	60	9	800	2.3	satisfactory
9	70	60	9	600	2.3	--- do ---
10	70	60	9	1250	2.3	less overlap
11	70	50	9	1500	2.3	No overlap
12	70	50	9	600	2.3	satisfactory
13	70	50	9	600	2.3	--- do ---
14	70	50	9	600	2.3	--- do ---
15	70	50	9	800	2.3	--- do ---
16	70	50	9	800	2.3	--- do ---
17	70	60	9	800	2.3	--- do ---
18	70	60	9	1000	2.3	--- do ---
19	70	60	9	1000	2.3	--- do ---
20	70	60	9	1000	2.3	--- do ---
21	70	50	9	800	2.3	satisfactory less weld width
22	70	50	9	800	2.3	--- do ---
23	70	60	9	800	2.3+	--- do ---

Note :	Sample Nos.	Shielding gas Argon	Flow rate
	1 to 20, 21, 22 and 23	N_2 80% + CO_2 20%	20 lit/min.

of the circle. Lifting of the foil was also noticed and the reason for this was traced to the distance between the weld line and the clamping line, which was 2mm and 1mm respectively for 6mm and 8mm diameter welds. In order to reduce the distance between the weld line and the clamping line to 0.5mm using the same fixture, welding over 9mm diameter was taken up. These specimens exhibited good weld beads on visual examination. While maintaining the focal point position of 2.3 on the scale and argon flow rate at 20 lit./min, the welding speed was varied from 600 to 1500 mm/min. Welds with good bead appearance were obtained at lower speeds viz. 600, 800 and 1000 mm/min. However at higher speeds of 1250 and 1500mm/min beads started appearing with reducing overlap. Three trials were also conducted at 800 mm/min. welding speed using a gas mixture of 80% nitrogen + 20% carbondioxide at 20 lit./min flow rate. Bead width was found to be smaller in these cases.

Covering the range of speeds, selectively specimens were examined by destructive metallography.



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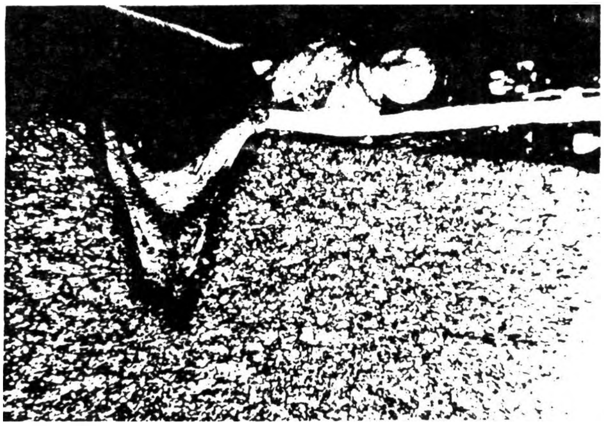

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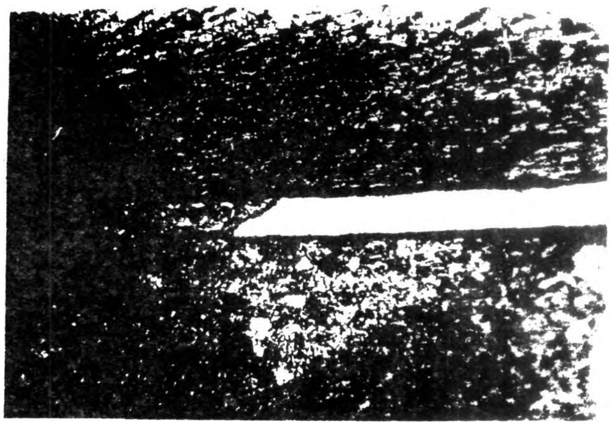
EXCESSIVE THINNING, EXCESS PENETRATION

Fig. 4 : Laser Weld Micrograph



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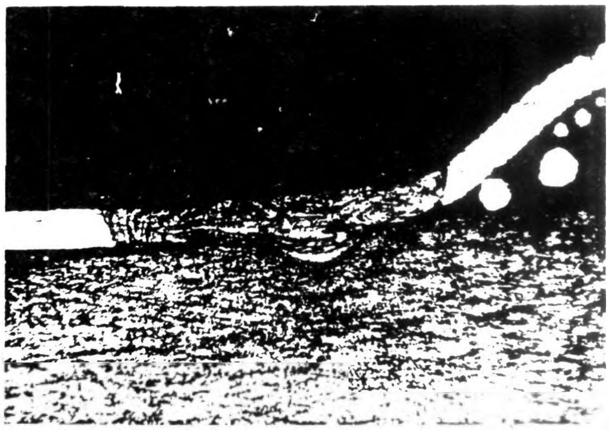
(a) : No fuson and penetration - poor weld



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(b) : Inadequate fusion and penetration

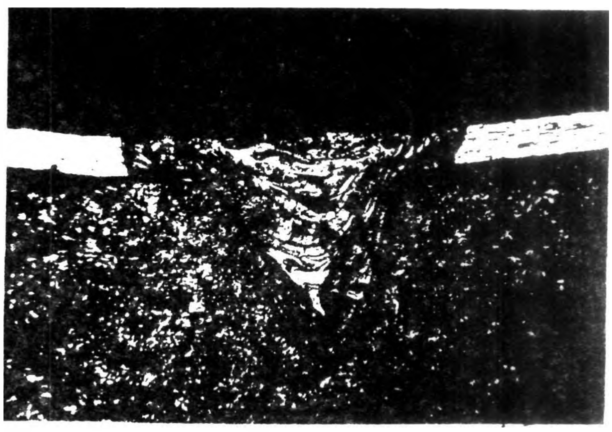

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Fig. 5 : Laser Weld Micrographs

Fig.5(a) shows micrography of the weld deposited at a speed of 100mm/min on 6mm diameter at 70mA current. The joint is poor with negligible fusion and no penetration. When the diameter was increased to 8mm, no reduction in wall thickness was noticed. Though the melting region of stainless steel is observed to be more. Fusion and penetration are however observed to be inadequate as seen in Fig 5(b)

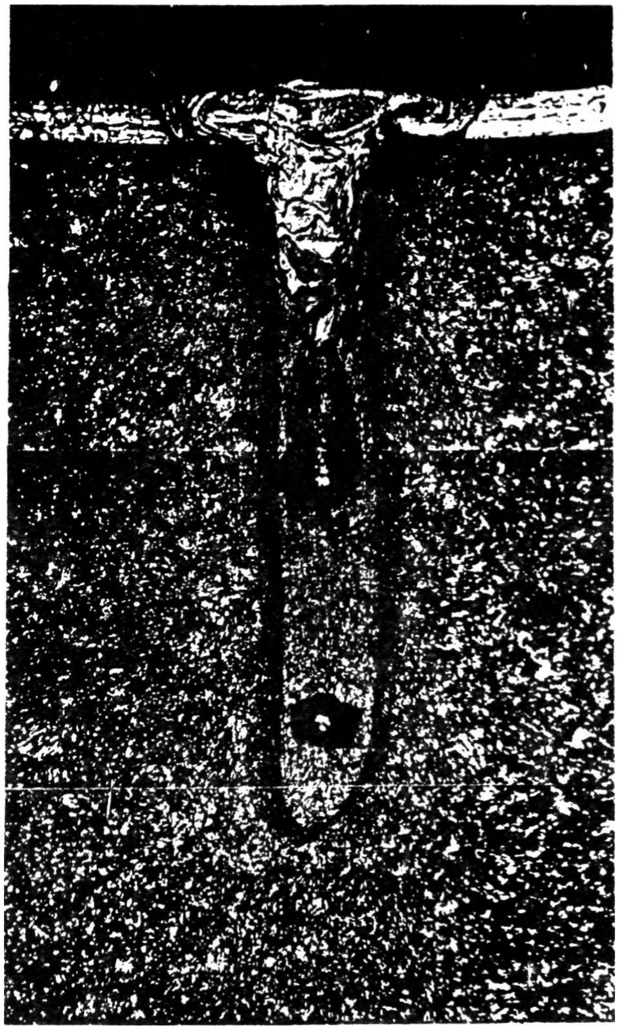
In order to move the weld line closer to the clamping line, the weld diameter was increased to 9mm, while maintaining the other parameters. Fig.5(c) shows the micrograph of this joint. There is no wall thickness reduction. Fusion and penetration are more. This is however closer to our requirement. While the parent metal hardness measured to be about 200 VPN, the microhardness measurements across the weld on specimen No. 3 indicated hardness of about 380 VPN.

An attempt was made to move the focal point position closer to the job. This gave rise to tremendous penetration as seen in Fig.6. No reduction in wall thickness is noticed.

Rupture Test

In order to establish the mechanical strength of the joint, some specimens were subjected to rupture test. Fig.7 shows the rupture disc burst test equipment which was designed and fabricated specially for this purpose. The equipment consists of a pressure barrel with a hydraulic pump connected through a flexible reinforced high pressure hose. A pressure gauge is connected in the line to read the rupture pressure.

A specially designed gasket consisting of a neoprene ring backed up by teflon rings was used in the rupture test sucessfully. It is pertinent to mention that the 0.6 micron surface



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EXCESS PENETRATION

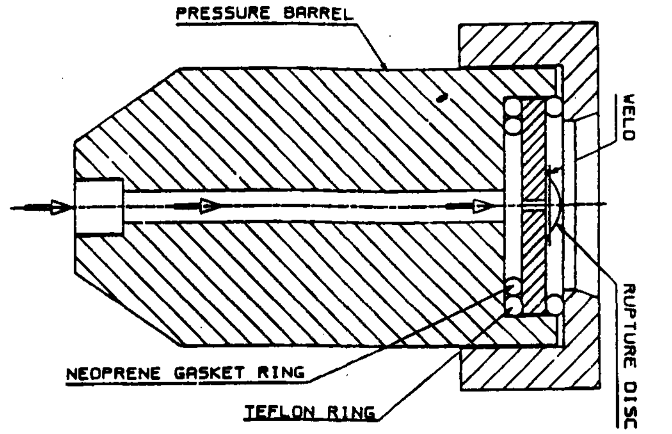
Fig. 6 : Laser Weld Micrographs

Table 3 : Rupture Disk burst test results

Specimen No. (refer table II)	Pressure Kg/cm²	Remarks
20	120	Gasket leak, cup formed
22	120	--- do ---
13	160	Brust despite gasket leakage
14	160	--- do ---
15	135	Burst (with teflon back up)
23	130	--- do ---
17	130	--- do ---
18	130	--- do ---

finish in the weld test pad is an essential requirement for effectively sealing the pressure during the rupture test.

The rupture test results are very encouraging as can be seen from Table3. the rupture tests indicate that the strength of the weld joint is adequate. Rupture disc failure was noticed in the parent metal close to the heat affected zone. The rupture pressure was in the range of 125 bars to 150 bars, approaching the requirement of 170 bars at 753K which is equivalent to about 200 bars at room temperature.



CONNECTION TO HYDRAULIC PUMP THROUGH FLEXIBLE REINFORCED HI PRESSURE HOSE

Fig. 7 : Rupture disc test equipment

CONCLUSION

1. For welding dissimilar metals with large thickness ratio in the range discussed in this paper using carbon dioxide laser, it is essential to ensure very good surface finish of the mating surfaces.
2. The clamping line must be chosen as close to the weld joint as possible to achieve sound weldsand to ensure mechanical strength of the weld joint is adequate.
3. This development work has been pogressing well. Since the rupture pressure is less than the requirement, the weld diameter needs to be reduced to about 6 or 7 mm to obtain the rupture pressure of 170 bars at 753K. Further work is planned in this direction to complete the remaining studies and finalize the welding parameters.