Chapter 31

Impact Angle Studies on Magnetic Pulse Welding of T91 tube to T91 end-plug

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The 2nd stage of DAE 3-stage nuclear power program envisage setting up of Fast Breeder Reactor (FBR) backed by reprocessing plant and fuel fabrication plant. The development of indigenous materials and manufacturing technology is vital for FBR programme. Ferritic/Martensitic such as T91 steel is candidate materials for metallic fuel FBR. The changes in material property during fusion welding of fuel pin are a potential issue that needs to be addressed. These properties also depends up on uniformed tempered martensitic microstructure for ferritic or martensitic steel and evenly distributed nano-sized oxide particles and precipitates, any microstructural disruptions induced by welding may change the property of the material. The welded microstructure can affect irradiation induced defect formation, leading to not only a change of yield stress but also a change of the dominant deformation mechanism and fracture mode. Radiation-induced hardening, swelling and radiation creep must all be considered in the welding [1-3]. There is a need to investigate and develop newer technologies for welding that limits the microstructure alteration. Magnetic pulse welding is one of the suitable options for this application [4].

31.1. Magnetic Pulse Welding of T91 tube – T91 end-plug

The T91 material has a yield strength 490 MPa, ultimate tensile strength 700 MPa and conductivity 1.35 MS/m. The chemical composition of T91 is shown in Table 31.1.

Table 31.1. Chemical composition of T91.

C	Si	Mn	P	S	Cr	Mo	Ni	V	Nb	N	Al
0.115	0.44	0.35	0.024	0.006	8.77	0.99	0.1	0.19	0.088	0.042	0.008

The T91 tube of 6.6 mm diameter and 0.45 mm thickness is to be welded with T91 rod to seal the end plug. The length and diameter of T91 end plug rod is 14 mm and 5.7 mm. The T91 rod is tapered on one side with a taper angle of 5^0 and 10^0, the length is 10 mm (Table 31.2). A stand-off distance of 1 mm is provided to accelerate the job piece (Figure 31.1).

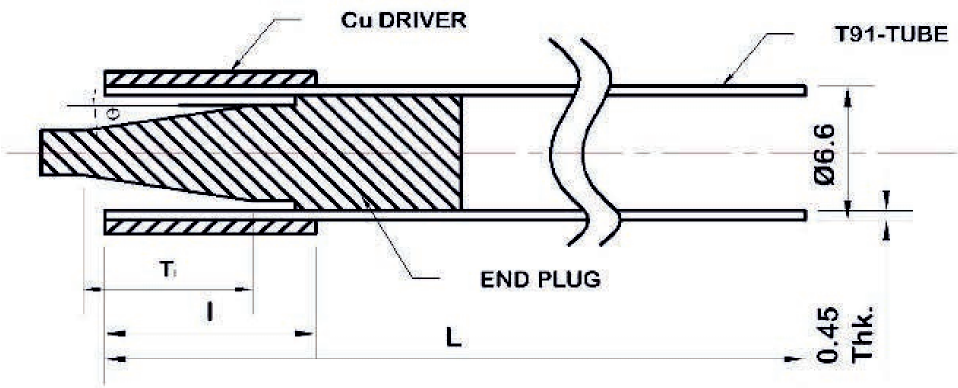

Figure 31.1. T91 tube and T91 end plug.

Table 31.2. Parameter of T91 tube and End plug.

Parameters	Dimensions in mm
T91 plug	14
Tapered length of T91 rod (T1)	8
Tapered angle	5 deg - 10 deg
Acceleration step	0.5

31.2. Single Turn Coil with Replaceable Insert

A single turn coil of SS alloy (SS-321) is made with replaceable copper insert in the centre. SS-321 stainless steel is Ni-Cr-Mo-type austenitic stainless steel, due to the addition of titanium, it has a better corrosion resistance and high temperature properties. The inner part of the coil is used to develop magnetic fields. So main design lies with the design of insert dimensions. The insert has been designed to weld the fuel pins having dimensions as shown in Table 31.3. Accordingly, the insert inner diameter is chosen as Ø8.8 mm after allotting required space for electrical insulation between insert inner surface and copper driver. The length of the working zone is chosen as 8 mm, from the weld length requirement. To prevent the voltage breakdown in the coil slit, electrical insulating films like polyamide films (Kapton) and Mylar are used. Similarly, insulations are used to isolate insert inner surface from copper driver. The placement of job piece in the coil is also shown in the Figure 31.2 and dimension of coils insert in Figure 31.3.

Table 31.3. Dimension of coil

S.No	Description of Parameter	Dimension
1	Outer Length of Coil (O.L)	60 mm
2	Central Length of Coil(C.L)	8 mm
3	Coil Diameter(C.D)	8.8 mm
4	D1 / D2	20 mm / 40 mm
5	D3 / D4	60 mm / 100 mm

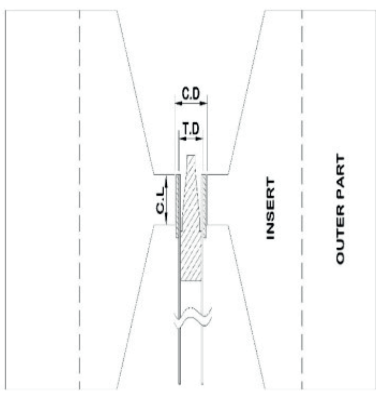

Figure 31.2. Schematic of job Piece.

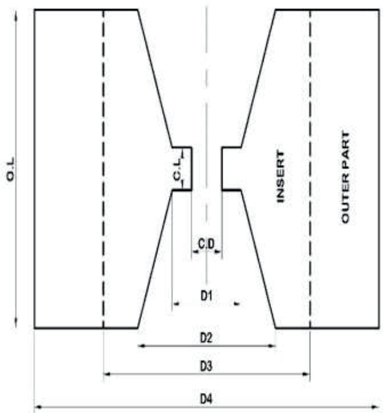

Figure 31.3. Schematic of coil.

31.3. MPW Experiment

The T91 tube and T91 rod were press fitted and placed inside the tool coil. 0.6 mm copper diver is placed on the T91 tube. The job pieces are rigidly fixed with delrin support to limit its movement during the impact. Constant current high voltage power supply is used to charge the capacitor bank [5]. Capacitor bank was charged up to 21 kV and discharges 830 kA at 34 kHz in the tool coil (Figure 31.4).

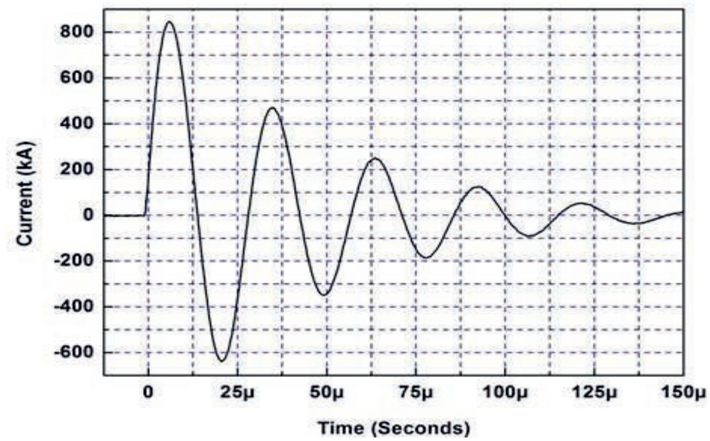

Figure 31.4. Tool coil discharge current of 830 kA.

The discharge current generates 52 T magnetic field inside the tool coil and exerts >1000 MPa pressure on the tube and accelerates it to impact the rod at higher velocities. The copper insert got deformed during weld and was replaced with new insert for next shot. The copper driver was removed from the tube by dissolving it in nitric acid. The weld produced was examined by non-destructive and destructive tests.

31.4. Interface Studies on 5^0 Taper Angle

For microstructural analysis an inverted metallurgical microscope was used. Before analysing the samples under the microscope, the welded samples are cut into sections containing the region of interest using an abrasive blade precision cutting machine. The cut sections are then moulded with Bakelite, followed by coarse polishing with SiC having grit sizes 300 to 1200 and then fine polishing on a synthetic cloth with diamond paste up to a finishing of 1µm. The polished samples were then etched with Villella's reagent before examining them under the microscope. It was observed that leaving ~1 mm from the start around ~2.5 mm of the interface has wavy morphology towards the tip of the tube. However, out of this ~1.7 mm has good bonding, labelled as 'b' in Figure 31.5.

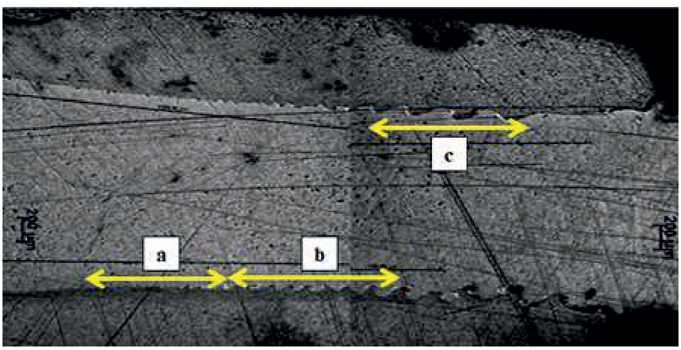

Figure 31.5. Weld interface.

Half cut longitudinal section as seen in Figure 31.5 indicates three different interface zones straight zone-a, regular wavy-weld zone-b and irregular wake zone-c. The transition of the weld interface morphology from a straight interface zone towards a wavy pattern represents the onset of instability kinematics in high velocity impact welding. During the interfacial instability the wavy pattern comprising of an upward and downward jetting is periodically formed and the wave height gradually increases with the progression of the collision. The impact angle intentionally provided on the target causes an oblique collision between the flyer and the target. The periodic wavy morphology at the interface further experiences an interfacial transition instability where the regular wavy pattern progresses towards an irregular interface pattern due to shear occurring both at the front and back of the unstable wave termed as the wake region. The interface joining might be attributed to mechanical mixing arising due to severe plastic deformation or to the temperature rise due to high impact velocity and atomic diffusion without melting.

Micro-hardness measurements with dead weight method were performed on the moulded and polished samples. The hardness values found at the tube was ~287 HVN, at interface was ~324 HVN and at end plug was ~275 HVN (Figure 31.6). This increase in interface hardness is considered negligible and is harmless as compared to hardness values witnessed in other conventional techniques.

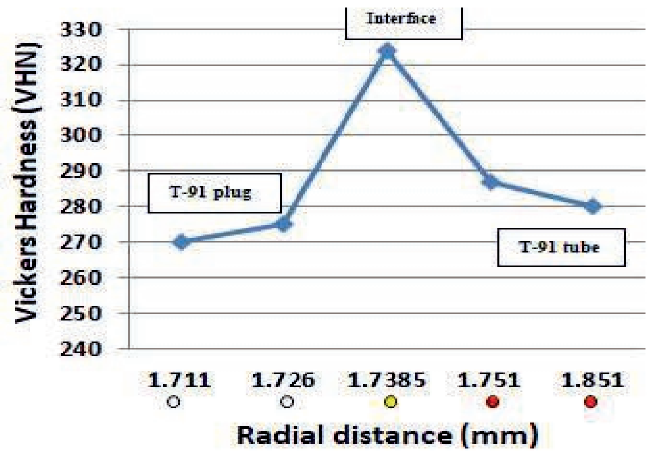

Figure 31.6. Vicker's Microhardness measured from T-91 plug to tube across the weld interface.

31.5. Interface Studies on 10^0 Taper Angle

Taper angle on end-plug was kept at 10^0 and magnetic pulse welding of T91 tube is done on T91 end plug with keep all parameters (electrical and geometrical) same expect for the taper angle. The weld pass helium leak test and give it of 4 x 10^{-10} mbar.l/s. Wavy interface bond of ~3.6 mm to ~4 mm seen with in between gaps of ~0.5-0.7 mm. The wavy interface bond is observed at a distance of ~3.8 mm away from T 91 end plug foot. Micro hardness at interface found is ~328 HV, tube it is ~284 HV and plug it is ~290 HV.

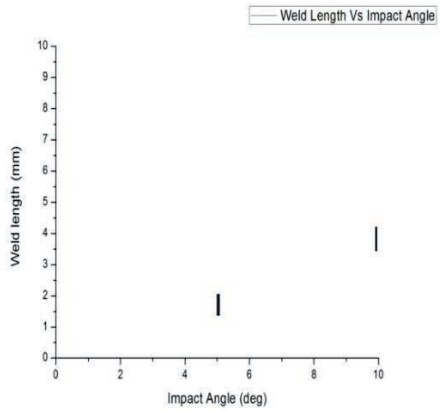

Figure 31.7. Weld length at impact angle.

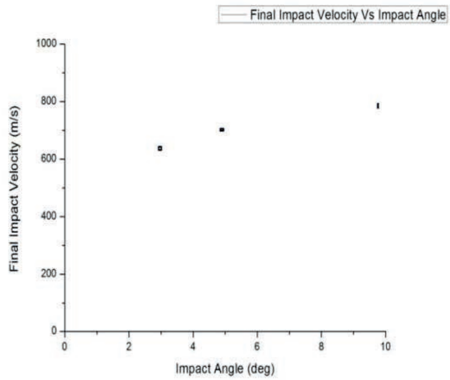

Figure 31.8. Impact velocity with impact angle.

MPW of T91 tube to T91 end plug was performed at 5^0 and 10^0 impact angle. In 5^0 impact angle the wavy interface of 1.5–2 mm was found 1 mm before the tip, from the simulation studies the maximum impact velocity of 660 m/s is achieved and the impact ends after 6.49 µs. In 10^0 impact angle the wavy interface of ~3.6 mm to ~4 mm seen with in between gaps of ~0.5-0.7 mm before 3.8 mm before the tip, from the simulation studies the maximum impact velocity of 750 m/s is achieved and the impact ends after 7.334 µs. Figure 31.7 represents the experimental weld length seen at 5^0 and 10^0 impact angle. Figure 31.8 represents the simulation of maximum impact velocity with change in impact angle**.**

Reference

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