

# Fabrication of Dummy Fuel Sub Assemblies (DFSA) for Core Mechanics Experiments

## EXECUTIVE SUMMARY

Dummy fuel sub assemblies (DFSA) will be instrumented to measure the displacement and interaction loads between the sub assemblies by simulating reactor condition. Hexagonal is the slenderest component in the DFSA and it is cold formed from the circular tubes. Alternatively, it was fabricated from sheet by forming in two halves and welded. Activated flux assisted Tungsten Inert Gas welding (A-TIG) is employed to join the long seam of hexagonal sheaths. 110 DFSA were manufactured meeting specifications. The A-TIG welding totally eliminates the need for edge preparation, filler wire addition and enhances the penetrating power in the weld pool. Hence, single pass weld with higher welding speed was achieved.

## OUTLINE

### Introduction

DFSA will be instrumented to measure displacement and interaction loads between sub assemblies to validate core restraint system design and to check the mechanical interlock along with grid plate sleeve. The actual fuel sub-assemblies for PFBR are manufactured from 20% cold worked D9 material by extrusion / pilgering process, which resists void swelling and irradiation creep. Due to non availability of cold formed hexagonal sheaths for the experiments, an alternative manufacturing method has to be evolved. Central workshop IGCAR does not have the pilgering facility; hence it was decided to fabricate the hexagonal sheaths by forming and welding. A novel A-TIG welding technology was developed and used in welding of hexagonal sheath.

### Fabrication of Hexagonal Sheath

The required sheet was sheared in Hydraulic Guillotine Shear with a dimensional accuracy of  $\pm 0.5$  mm. The hexagonal shape was bent in press brake machine in three stages using conventional die and modified punch. The edge preparation was done by manual grinding due to less thickness and geometry of hexagonal. A special welding fixture was made to control mismatch and distortion during welding. The GTAW process was used. Distortion is inevitable in austenitic stainless steel welding due to high thermal expansion ( $17 \times 10^{-6}$  m / m °K) and low thermal conductivity ( $16.3$  W/m°K). The distortion will affect the geometrical tolerance of the component. The combination of controlled heat input ( $\leq 1000$  J / mm), sequential welding and use of appropriate welding fixture, the distortion was controlled to minimum. The inter pass temperature was maintained less than 393°K. In GTAW process, the production rate is less due to limitation in the welding speed.

### Development of A-TIG

Material Joining Section (MJS) of IGCAR has developed activated flux for GTAW process and it will enhance the penetration in the weld pool. The development has been proven in laboratory level. The laboratory level proven technology was applied successfully on production scale. The activated flux which is in paste form was applied on the seam joint as shown in Figure 1. During welding activated flux changes the convection movement in the weld pool from centrifugal to centripetal as shown in the Figure 2 and there by deep penetration is achieved. The non destructive test DPI, RT / UT was carried on A-TIG welded sheaths. The destructive testing like, tensile test and bent tests were also carried. The micro hardness test was carried out on the welded samples from GTAW and A-TIG. The micro structure analysis revealed that the weld metal has columnar dendritic microstructures. The micro hardness measurements have shown good ductility in the A-TIG weld metal. A-TIG welded specimens have also passed intergranular corrosion tests (ASTM A262 practice A & C). The delta ferrite examination was also carried out on the A-TIG welded sheaths. The DT & NDT test results were meeting all the design requirements and also a considerable welding time was saved by 70 % as compare to conventional method. So, the hexagonal sheaths were welded using A-TIG welding process.



Fig. 1 : Photograph of A-TIG welding under progress in hexagonal sheath

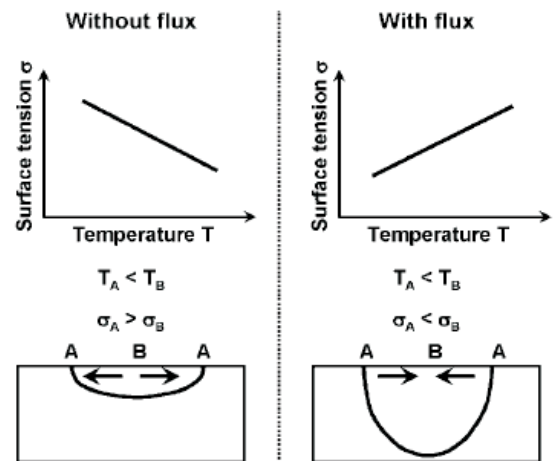


Fig. 2: Schematic diagram of Marangoni Convection

## ■ WHAT IS ATIG WELDING

An effective improvement in the GTAW process termed Active Tungsten Inert Gas (A-TIG) welding. Before welding, a fine layer of an inorganic powder, known as activating flux is deposited on the surface to be welded. The resulting depth of penetration is increased by a factor of 1.5 to 4 in comparison with the penetration depth

## ■ GENERAL DESCRIPTION

Dummy fuel sub assemblies (DFSA) will be used for experiments. Hexagonal is the slenderest component in the DFSA and it is cold formed from the circular tubes. Alternatively, it was fabricated from stainless steel sheet by forming in two halves and welding. GTAW process was used for welding of hexagonal sheath and production rate is less due to limitation in the welding speed. Material Joining Section (MJS) of IGCAR has developed activated flux for GTAW process and it will enhance the penetration in the weld pool as shown in Figure 3. The laboratory level proven technology of Activated flux assisted Tungsten Inert Gas welding (A-TIG) was applied successfully on production scale to join the long seam of hexagonal sheaths. 110 DFSA were manufactured meeting specifications. The A-TIG welding totally eliminates the need for edge preparation, filler wire addition and enhances the penetrating power in the weld pool with controlled distortion. Hence, single pass weld with higher welding speed was achieved. It increases the production rate by three times as compared to conventional GTAW process.

Without activated flux



With activated flux

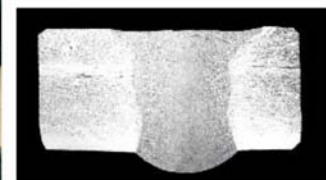
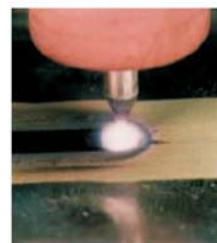


Fig. 3 : Photograph of Weld without / with activated flux

## ■ MECHANISM OF ATIG

There are two mechanisms that play important role in activating the effect of flux.

- 1) Marangoni effect: It refers to the convection movements due to the surface tension gradient on the weld pool surface. During TIG welding the surface tension gradient is negative and the convection movements are centrifugal and it leads to shallow penetration. The addition of activated flux induce an inversion of the convection currents changing the sign of the surface tension gradient, resulting convection movements changed to centripetal. Hence, the penetration depth increases.
- 2) The arc constriction effect: a) The flux acts as an insulating layer reducing the current density at the outer radii of the arc column and thus increases the current density at the center, increased magnetic force which leads to strong convective flow downwards in the weld pool and thus to significantly increased weld depth. b) The flux powder (Titanium dioxide) also causes the formation of an anode spot on the surface of the joint which attracts the electrons from the cathode (Tungsten electrode) causing deeper penetration. c) Negative ion formation at the edge of the arc could increase current density at the centre of the anode and thus increase the weld depth. It increases the production rate by three times as compared to manual GTAW process and it gives consistent quality and excellent bead appearance.

## ■ ACHIEVEMENT

The developed and laboratory proven activated flux technology was applied successfully on production scale. The flux assisted welding totally eliminates the need for edge preparation, filler wire addition and enhances the penetrating power in the weld pool with controlled distortion. Hence, single pass weld with higher welding speed was achieved. It increases the production rate by three times as compared to manual GTAW process and it gives consistent quality and excellent bead appearance.

## ■ PUBLICATIONS ARISING OUT OF THIS STUDY AND RELATED WORK

1. P. Sivaraman, M. Krishnamoorthy, N. Easwaran, R. Veluswamy and A. S. L. Kameswara Rao, International Symposium on Advances in Stainless Steels – 2007.

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