Nuclear Power for Clean Energy

IN SERVICE TO THE WELDING COMMUNITY

HIGHLIGHTS

- INDIAN PRESSURIZED HEAVY WATER REACTOR (PHWR)
- APPLICATION OF HARDFACING IN NUCLEAR VALVES
- CONSUMABLE WELDING INSERTS
- WELD PURGING IN CRITICAL POWER PLANT SYSTEMS
- NEW PRODUCT
Dear Readers,

After highlighting the achievements of the Indian Space Industry in our last issue, we are pleased to place Weldwell Spectrum Volume 26 (combined issue) # 1 and 2. This special issue is dedicated to “Nuclear Power in India”. India has the seventh largest nuclear power production fleet in the world and Welding plays a significant role in the fabrication of nuclear components. Therefore, the importance of this topic cannot be over-stressed. With the large number of operating and under construction of Indian Pressurized Heavy Water Reactors (IPHWR), it is naturally the focus of this issue.

We are indebted and grateful to Shri Ashok Gore, Former Sr. Executive Director (Operation), NPCIL, who spared his valuable time and guided us in editing, especially the lead article. Our sincere thanks are also due to Mr. Pradip Goswami, Welding Consultant, Canada, and Dr. J. Krishnan, Professor, L&T Welding Chair, M.S University, Vadodara, and other professionals with vast experience in the nuclear industry, for their technical inputs.

The lead article ‘Indian PHWR and Major Nuclear Components’ provides an insight into the present scenario in India and the salient features of the Indian PHWR and the major nuclear components thereof.

“Application of Hardfacing in Nuclear Valves” provides a broad-based overview of hardfacing alloys and processes used in nuclear plants, specifically, nuclear valves.

“Weld Purging in Critical Power Plant Systems” discusses the importance of purging in welding of critical joints and the engineered solutions available.

“Consumable Welding Inserts” are considered a boon for high-integrity nuclear piping joints. Their classification and usage are discussed in this article.

We, once again thank our contributors for making this issue ‘Special’. Readers are requested to offer suggestions and/or comments to help us make your newsletter more interesting and informative.

Best wishes for continued publication of Weldwell Spectrum!

Ashok Gore
(Former Senior Executive Director - NPCIL)

A large number of Pressurized Heavy Water Reactors are presently under construction in India and many more are being planned. Addition of many large capacity Light Water Reactors with foreign collaboration is also expected in the near future. In short, the nuclear power programme in India is poised for quick expansion.

‘Make in India’ has been a major driving force of this programme since its inception. Indigenous fabrication of nuclear components requiring sophisticated welding techniques has been a success story. Exposure of the Indian industry to stringent quality control and related processes has been a significant spin off of this success story. The benefits have percolated to the non-nuclear industry as well. Hence, it is appropriate that this issue of Weldwell Spectrum is dedicated to ‘Nuclear Power in India’.

Although, an outsider as far as welding is concerned, I had a fortuitous exposure to this interesting field after joining the Department of Atomic Energy in 1968. I continue to be an outsider, but one with a few fond memories of related activities in the past.

Recently, these memories were revived while working with members of the Editorial Team of M/s Weldwell Speciality for this edition of Weldwell Spectrum. It was a very pleasant and, to a certain extent, educative experience.

Best wishes for continued publication of Weldwell Spectrum!

Ashok Gore
(Former Senior Executive Director - NPCIL)
Brief Introduction
Availability of adequate energy resource in general and electrical energy in particular is essential for development and sustenance of any nation in modern times. During the last sixty years, nuclear power has progressively made a significant contribution in many countries in the world. Nuclear power is expected to continue to be a significant source of energy in the foreseeable future.

The scenario in India:
Dr. Homi Bhabha, the founder of India’s nuclear programme, recognized the importance of nuclear power for India and was instrumental in planning and establishing the requisite infrastructure for this and allied purposes. He summed it up by stating “No power is costlier than no power”. Accordingly, the Atomic Energy Commission (AEC) and the Department of Atomic Energy (DAE) were constituted in 1948 and 1954 respectively followed by establishment of a number of entities/organisations to provide various inputs required for the envisaged programme.

Uranium – 235, Plutonium – 239 and Uranium – 233 are fissile materials that are used as nuclear fuel. Plutonium – 239 can be produced from Uranium – 238, a fertile material. Similarly, Uranium – 233 can be produced from Thorium – 232, another fertile material. India has very limited deposits of natural uranium that contains about 0.7 % Uranium – 235 and the rest is Uranium – 238. However, it is blessed with huge deposits of thorium. Hence, it was planned to use natural uranium as nuclear fuel to start with and opt for a type of nuclear power reactor technology that was available or could be readily developed indigenously. Consequently, a plan specifically tailored to meet India’s requirements and constraints, was envisaged in the form of a three stage programme as follows:

Stage # 1
Construction and operation of Pressurised Heavy Water Reactors (PHWRs) using natural uranium as nuclear fuel with heavy water as the moderator and subsequent separation of Plutonium – 239 from the spent fuel.

Stage # 2
Construction and operation of Fast Breeder Reactors (FBRs) using Plutonium – 239 as nuclear fuel and Thorium – 232 in the core blanket to produce Uranium – 233 and subsequent separation of Uranium – 233 from the core blanket. FBRs are capable of generating more fuel than what they consume. A 500 MWe Prototype Fast Breeder Reactor (PFBR) has been constructed and is expected to be commissioned in the near future.

Stage # 3
Construction and operation of FBRs using uranium – 233 as nuclear fuel and thorium – 232 in the core blanket to produce uranium – 233 and subsequent separation of uranium – 233 from the core blanket. Operation of Advanced Heavy Water Reactors (AHWRs), which will have Thorium – 232 in the fuel, is also envisaged. Construction of a prototype AHWR with advanced safety features is expected to be taken up in the near future.

The first PHWR belonging to CANDU (Canadian Deuterium Uranium) family of reactors was set up in 1973 at Rawatbhata near Kota in Rajasthan with Canadian collaboration as unit # 1 (initially rated as 200 MWe) of Rajasthan Atomic Power Station. Experience gained during this process enabled DAE to evolve indigenous design of a series of Indian PHWRs rated as 220 MWe, 540 MWe and 700 MWe over a period of time. Accordingly, a large number of PHWRs are presently operational and a few PHWRs are under construction.

During 1980s, DAE decided to opt for the construction of large capacity light water nuclear power plants with foreign collaboration for faster addition to the country’s nuclear power generating capacity. Also, after signing of the ‘Indo – US agreement for cooperation concerning peaceful uses of nuclear energy’ (commonly known as 123 Agreement), a path was opened for signing of similar agreements with other countries during the second half of the last decade. As a result, construction of a large number of high capacity light water reactors with American, Russian and French collaboration is envisaged. Two 1000 MWe Pressurized Water Reactors, built with Russian collaboration, are presently operational at Kudankulam near Kanya Kumari. The present nuclear capacity is about 6780 MWe from 22 operating reactors. As per current indications, the total nuclear capacity is likely to be about 22.5 GWe by the year 2032.
Natural uranium oxide is used as fuel and heavy water is used as both the coolant and moderator in separate circuits. Fuel bundles are arranged in horizontal pressure tubes through which high pressure coolant heavy water is pumped. The pressure tubes are located within a large tank called the Calandria that contains low pressure moderator heavy water. This design allows on line refuelling of the reactor. Pressurized heavy water, the primary coolant, is pumped through the fuel channels via headers and feeders. It picks up heat produced by fission in the fuel bundles, passes through the outlet feeders and headers and goes through tube bundles in the steam generators where the heavy water coolant transfers its heat to light water (feed water) flowing into the shell side of steam generators producing light water steam. The steam from the steam generators is sent to the turbine. The primary coolant coming out of the steam generators goes to the PHT pumps which send it back to the inlet headers and feeders to start the next cycle.

The fission chain reaction is controlled/shut down using a variety of neutron absorbing rods in the reactor core. A light water Liquid Zone Control system is used for effecting normal increase/decrease of reactor power level in 540 MWe & 700 MWe PHWRs.

The reactor building has a double walled containment for radiation shielding and prevention of the leakage of radioactivity to the external environment.

Normal access to and from the reactor building is controlled by the main airlock. A smaller airlock is provided for use in emergencies.

**Major Nuclear Components in Indian PHWRs**

**Introduction**

A typical Nuclear Power Plant (NPP) consists of essentially two parts: The nuclear island in which all major nuclear systems/components are installed and the other part for conventional systems/components. The nuclear island has a leak tight enclosure that also acts as a radiation shield. The Nuclear Steam Supply System (NSSS) in the nuclear island supplies steam to the turbine installed in the conventional part. The following three requirements are of paramount importance in an NPP:

1. The reactor power is always to be controlled at safe levels to prevent an uncontrolled nuclear chain reaction.
2. Capability to shut down the reactor and to maintain it in safe shutdown condition along with adequate cooling of the nuclear fuel.
3. To prevent the release of radioactivity to the environment beyond the permissible levels stipulated by the regulator.

Consequences of a nuclear accident are serious having long term effects. Hence, it is necessary that various systems/components in an NPP, especially those in the nuclear island, are designed and fabricated with the highest possible quality standards and operated with extreme care so as to assure safety of the plant and its surroundings. Certain aspects pertaining to the material requirement, size and fabrication of major components of NSSS and a few other nuclear systems in the nuclear island of an Indian 700 MWe PHWR are briefly covered below.

**The Reactor Assembly**

The reactor assembly comprises of a horizontal cylindrical vessel (called ‘calandria’) closed at each end by end shields. The end shields support a number of horizontal fuel channels (coolant channels) that span the calandria through its lattice tubes (calandria tubes). The fuel channels, through which high pressure heavy water flows, contain fuel bundles. The coolant channel assembly of a PHWR comprises mainly of a pressure tube, concentrically located inside a calandria tube with the help of garter spring spacer supports evenly mounted along its length. All these components are made of zirconium alloys.

**Calandria**

The calandria is a cylindrical vessel fabricated using 304L stainless steel plates, bars and forgings meeting ASME Section II, part A requirements. It is about 9 metres in diameter and weighs about 80 MT. Calandria assemblies are fabricated, machined, inspected and tested as per Sub-section NB of ASME Section III. Welding procedures used in the fabrication of calandria are qualified as per ASME Section IX and all welds are 100% radiographed. Calandria fabrication involves distortion control, development of specific welding procedures and precise machining. Extensive knowledge of functioning, fabrication, distortion, sequencing, etc is required to meet the stringent requirements. Besides the horizontal calandria lattice tubes, a number of other tubes that
penetrate the calandria shell are also provided for various reactivity control elements. The space between these tubes and the calandria shell is filled with heavy water which acts as the moderator of fission neutrons.

**End Shields**

Two massive end shields, one at either face of the calandria, are important parts of the nuclear reactor assembly. Each end shield weighs about 120 MT and is made of SS 304L. Each end shield is a cylindrical box closed by the calandria side tube sheet (55mm thick) and the fuelling machine side tube sheet (80 mm thick). The box is pierced by 392 lattice tubes arranged on 286 mm square lattice and is filled with 10 mm dia carbon steel balls and light water to provide radiation shielding. End shields are welded to the calandria shell at both ends in situ at the plant site.

The outer sub-assembly of an end shield consists of a cylindrical outer shell of 8088 mm ID, which is concentric with the main shell, and two end flanges welded to it to form an ‘H’ section. The outer edges of the end flanges are octagonal in shape (A/F 9110 mm). The inner edges of end flanges are machined circular and welded to the extensions of fuelling side tube sheet and calandria side tube sheet. The portions of end flanges and extensions of tube sheets between the outer shell and the main shell are machined to the thickness of 24 mm to serve as flexible diaphragms.

**Reactor Headers**

Reactor inlet and outlet headers are pressure vessels with nozzles for welded connections to corresponding feeder pipes and PHT pumps. They have ellipsoidal dished ends.

Inlet header: 457 mm OD, 65 mm wall thickness. Outlet header: 508 mm OD, 65 mm wall thickness.

Length: 14.7 metres, Weight: about 10 T (header forging), about 14 T (full header assembly).


Welding: All weld joints are full penetration welds. Consumable Y type inserts are used for root welding. All welding procedures, welders and welding operators are qualified in accordance with the nuclear code.

**Pressuriser**

The pressurizer is a vertical pressure vessel with a bottom nozzle to accommodate an in surge of the reactor primary coolant. It contains electric heaters at
A steam generator consists of a vertical drum with integral cylindrical heat exchanger which houses a U-tube bundle and an annulus recirculation path between the shroud of the U-tube bundle and the heat exchanger pressure boundary. It is connected to the PHT system heavy water on the primary side and to the conventional light water steam systems on the secondary side. It is designed, fabricated, examined, and tested to meet the requirements of ASME Section-III, NB-Class-1 for both primary and secondary sides.


Total length: about 24 metre.

**Moderator System**

The space in the calandria, outside the lattice tubes is filled with heavy water. This heavy water acts as a moderator to slow down neutrons emitted during the fission process in the fuel bundles. Pumps and heat exchangers are provided to circulate and cool the moderator heavy water. This is a low pressure, low temperature system. However, system leak tightness is necessary as it contains highly radioactive heavy water.

**Fuel Handling System**

The fuel handling system refuels the reactor without interrupting normal reactor operation. It can remove spent fuel bundles from any fuel channel and load new fuel bundles into it. It also provides temporary storage of new and irradiated spent fuel bundles. The system is designed to refuel the reactor at any power level. There are two bidirectional fuelling machines, one at either end of the reactor, which operate in tandem. Fuelling machine heads latch on at the two ends of a fuel channel to load or remove fuel bundles from that channel. These heads can travel to any fuel channel which is to be refueled.

**Quality requirements**

To summarize, very stringent quality standards are required to be followed for the design and fabrication of major nuclear systems and components. From an industrial standpoint, the core issues of such quality requirements while executing fabrication of the concerned equipment are addressed by adopting the framework of ‘Quality Assurance Programme (QAP)’. The features of a QAP are as follows:

- Design Control; Procurement Document Control; Instructions, Procedures and Drawings; Document Control; Control of Purchased Material, Equipment and Services; Control of Special Processes; Nonconforming Materials, Parts or Components; Handling, Storage and Shipping.

Indian nuclear programme has contributed significantly to fabrication processes in Indian industry. While executing fabrication of nuclear components, the Indian industry got exposure to the culture of following stringent quality standards and associated practices. This has resulted in a good impact in non-nuclear fields as well.

**Editorial Comment**- Indian industries have gained extensive expertise and made India totally self-reliant in PHWR technology. There are now more than a thousand organizations both private and public, which have risen to the occasion, and are capable of manufacturing internationally comparable, nuclear grade equipment.

Overall Impact of Interaction with Indian Industries - This has enabled India to operate nuclear plants reliably and safely, despite technology regimes and reduced foreign exchange content to 10%.
INTRODUCTION:

Valves are an important and integral part of the process system in any Nuclear Power Plant. Valves are critical components for regulating the flow of process fluids. Due to their location within the piping isometric loop and due to their nature of operations valves are often degraded by hot erosion, accelerated wear, corrosion and other tribological degradation processes. Nuclear valves are typically made by forging or casting process. Valve seats often take the major impact of operating conditions and process fluids. Application of hardfacing alloys on the seats improves resistance to wear and galling, increases leak tightness and improves the service life of valves to a great extent. In nuclear plants, cobalt-based hardfacing alloys, such as Stellite®, had been used for many years because of their excellent weldability and wear resistance. At the same time many other alloys have been tried over the years.

This article provides a thorough review of such hardfacing alloys, their merits and demerits under various operating conditions in Nuclear Power Plants stations. The choice of such alloys could be many. However, efforts have been made to provide a brief description of proven hardfacing alloys used for PHWR valves.

Analysis of Hardfacing Materials:

Hardfacing materials are required in several components of nuclear power plants. The temperature, corrosion and wear conditions are clearly different in different systems of the plants. Common hardfacing alloys used in PHWR nuclear environments are classified as below and are of immense importance for valves.

a) Cobalt-Based Alloys -

This grade of alloys based upon cobalt-chromium (Co-Cr) specially designed for abrasion resistance. There are many alloys under this brand. However, in the context of the power plants (both nuclear and Non-Nuclear) Stellite-6® is the most commonly used alloy in this category. This is an alloy with excellent resistance to many forms of mechanical and chemical degradation and maintains a high hardness value up to 800°C, it also has high resistance to erosion by cavitation or impact. This alloy is particularly suitable for a wide variety of hardfacing surfaces and is machinable by carbide cutting tools. Stellite-6 is widely used, for example, on valve seats, shafts and pump bearings, or parts subjected to erosion. It may be deposited by Plasma Arc (PTAW), GTAW, or by GMAW process, or by laser cladding.

Unfortunately, the presence of Cobalt in Nuclear reactors leads to its activation leading to Co60 isotope, emitting high energy gamma radiation. Hence, despite their excellent service records “Stellite” has some limitations due to “additional radiation” in Nuclear systems. However, these alloys are extremely safe for operation in Non-Nuclear systems of nuclear plants.

b) Nickel-based alloys

Colmonoy® is a nickel-based alloy which comprises of hard- chromium borides and carbides. Nickel hardfacing alloys were developed as substitutes for cobalt alloys in an effort to avoid the high radiation intensity generated by cobalt-60 isotopes. It also results in cost reduction. Its main objective is to be cobalt free while providing different grades adapted to different wear and corrosion conditions. Hard facing of stainless & other steels, with these nickel-based alloys were adopted for various nuclear components to minimize induced radioactivity during maintenance, component handling and decommissioning. However operating experience throughout the nuclear industry has shown that the nickel-based hardfacing alloys used in moderator system valves corrode faster in the low pH values. Valves and valve seats in nuclear reactors are common applications involving colmonoy. A brief snapshot of compositions of various grades of Nickel Based alloys for Nuclear Valves is presented below in Table-2.

c) Iron-Based Alloys -

The Norem® alloy is an iron-based hardfacing alloy without cobalt. It was developed by Electric Power Research Institute (EPRI) as a substitute for Stellite in PWR and later used extensively in PHWR systems. EPRI holds the proprietary rights for these alloys. This iron-based alloy offer exceptional resistance to galling (adhesive) and cavitation type of erosion. Norem is finding steady and wider use in many applications in nuclear power plants, hydroelectric, and fossil fuel plants. Norem may be deposited by different welding processes. However, in the context of nuclear valves, seating surfaces are deposited by PTAW and GTAW and by GMAW in some instances. Chemical composition of a few grades of Norem Alloys is listed in Table-3.
Hardfacing Deposition Processes:

Hardfacing is a surfacing variation in which surfacing material is deposited to reduce wear by increasing the resistance of a metal surface to abrasion, impact, erosion, galling, or cavitation. The important and required properties of hardfacing alloys in nuclear environment are hardness, abrasion resistance, impact resistance, erosive wear resistance, heat resistance and corrosion resistance. Hardfacing alloys could be deposited by a number of processes. Most commonly used Arc Welding processes for deposition on valves are, Plasma Transferred Arc Process (PTAW), Gas Tungsten Arc Welding Process (GTAW). A generic comparison of both the processes are as below. Typically valve manufacturers choose a combination of the following arc welding processes.

### Table-1, Compositions of Stellite®-6 hardfacing alloy

<table>
<thead>
<tr>
<th>Stellite Grade</th>
<th>Co</th>
<th>Ni</th>
<th>Fe</th>
<th>B</th>
<th>C</th>
<th>Cr</th>
<th>Si</th>
<th>W</th>
<th>Rockwell Hardness (HRC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Bal</td>
<td>&lt;3</td>
<td>&lt;3</td>
<td>1.2</td>
<td>28</td>
<td>1.1</td>
<td>4.5</td>
<td></td>
<td>36-45 HRC</td>
</tr>
</tbody>
</table>

### Table-2, Compositions of Colmonoy® hardfacing alloy

<table>
<thead>
<tr>
<th>Colmonoy Grade</th>
<th>Ni</th>
<th>Fe</th>
<th>B</th>
<th>C</th>
<th>Cr</th>
<th>Si</th>
<th>Rockwell Hardness (HRC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Bal</td>
<td>2.8</td>
<td>2.1</td>
<td>0.4</td>
<td>10.0</td>
<td>2.4</td>
<td>35-40</td>
</tr>
<tr>
<td>5</td>
<td>Bal</td>
<td>4.8</td>
<td>2.1</td>
<td>0.45</td>
<td>13.8</td>
<td>3.3</td>
<td>45-50</td>
</tr>
</tbody>
</table>

### Table-3, Compositions of a Few Norem grades and related welding processes. Composition: weight %, % Fe is Balance.

<table>
<thead>
<tr>
<th>Alloy grade</th>
<th>Process</th>
<th>C</th>
<th>Si</th>
<th>Cr</th>
<th>Mn</th>
<th>Ni</th>
<th>Mo</th>
<th>N</th>
<th>P</th>
<th>S</th>
<th>B</th>
<th>O</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>02</td>
<td>PTAW</td>
<td>1.1-1.35</td>
<td>3.1-3.5</td>
<td>23-26</td>
<td>4.0-5.0</td>
<td>3.7-5.0</td>
<td>1.8-2.2</td>
<td>&lt;0.18</td>
<td>&lt;0.020</td>
<td>&lt;0.010</td>
<td>&lt;0.002</td>
<td>&lt;200 ppm</td>
<td>Galling</td>
</tr>
<tr>
<td>02A</td>
<td>GTAW</td>
<td>1.1-1.35</td>
<td>3.1-3.5</td>
<td>23-26</td>
<td>4.0-5.0</td>
<td>3.7-5.0</td>
<td>1.8-2.2</td>
<td>&lt;0.06</td>
<td>&lt;0.020</td>
<td>&lt;0.010</td>
<td>&lt;0.002</td>
<td>&lt;200 ppm</td>
<td>Galling</td>
</tr>
<tr>
<td>03A</td>
<td>GMAW</td>
<td>0.9-1.2</td>
<td>2.4-3.2</td>
<td>20-23.5</td>
<td>3.5-4.5</td>
<td>4.0-5.0</td>
<td>1.7-2.2</td>
<td>&lt;0.1</td>
<td>&lt;0.020</td>
<td>&lt;0.010</td>
<td>&lt;0.006</td>
<td>&lt;200 ppm</td>
<td>Galling</td>
</tr>
<tr>
<td>03B</td>
<td>GMAW</td>
<td>0.7-1.1</td>
<td>2.2-3.0</td>
<td>20-24</td>
<td>3.0-4.0</td>
<td>4.0-5.0</td>
<td>1.7-2.2</td>
<td>&lt;0.1</td>
<td>&lt;0.020</td>
<td>&lt;0.010</td>
<td>&lt;0.006</td>
<td>&lt;200 ppm</td>
<td>Cavitation/Erosion</td>
</tr>
</tbody>
</table>

### Hardfacing Deposition Processes:

Hardfacing is a surfacing variation in which surfacing material is deposited to reduce wear by increasing the resistance of a metal surface to abrasion, impact, erosion, galling, or cavitation. The important and required properties of hardfacing alloys in nuclear environment are hardness, abrasion resistance, impact resistance, erosive wear resistance, heat resistance and corrosion resistance. Hardfacing alloys could be deposited by a number of processes. Most commonly used Arc Welding processes for deposition on valves are, Plasma Transferred Arc Process (PTAW), Gas Tungsten Arc Welding Process (GTAW). A generic comparison of both the processes are as below. Typically valve manufacturers choose a combination of the following arc welding processes.

### Table-4, Comparison of Popular Hardfacing

<table>
<thead>
<tr>
<th>Process</th>
<th>Thickness (typical)</th>
<th>Geometrical complexities</th>
<th>Quality of the Deposit</th>
<th>Bonding to Substrate</th>
<th>Residual Stress -Deformation</th>
<th>Dimensional Accuracy</th>
<th>Operation cost + material</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTA</td>
<td>100μm</td>
<td>Complex, 3D geometries</td>
<td>Medium</td>
<td>Medium</td>
<td>Very low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>GTAW</td>
<td>1mm</td>
<td>Simple 3D geometries</td>
<td>Good</td>
<td>Very Good</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
Conclusions:
Valves act as barriers, controlling devices for fluid flow in any process environments. Hardfacing of valves involves precise and complex surfacing processes. Control of weld dilution, hardfacing chemistry, dimensional/distortion control, quality of surface finish all are important. In absence of quality hardfacing on the valve seats and adjoining surfaces leakage (passing) are inevitable which upsets the process parameters and efficiencies. Also in the context of nuclear plants such leakages generate serious operational health and safety issues.

As hardfacing progressively deteriorates over years of service, due to erosion, galling and other mechanisms, selection and successful deposition of the correct hard facing alloys are extremely important. This article discussed and provided a broad-based reviews and overview of hardfacing alloys used in PHWR-Nuclear Plants. Hope these intentions were achieved in this article.

*A Brief Introduction of the Author: -

The author is a well experienced welding & metallurgical engineering specialist and consultant, with over 35 years of varied experiences, in Nuclear, Oil & Gas, Refining and Petrochemicals Industries. He may be contacted through LinkedIn or the email as provided here. Currently he works as a consultant to a Canadian (Global) EPCM organization, based in Toronto.
Consumable Welding Inserts
A Boon for high integrity welds in Nuclear Piping

Introduction:
The construction and repair of nuclear power facilities requires critical welding with precise control. Gas tungsten arc welding is used in industries where uniform root penetration is desired and can be used to weld almost all metals. High quality weld deposits and relatively low-cost equipment have made GTAW an indispensable tool in many industries. However, it has limitations including low deposition rates and limited penetration capabilities. At material thicknesses greater than 3 mm, penetration capabilities of the process become questionable. Applications such as welding for end closure caps, plugs to fuel rods, the air-tight sealing of the end closures on fuel rods etc. accessibility is restricted to one side only. In addition, internal obstructions cannot be tolerated, high quality root pass, uniformity and smooth bead is required. A solution in the form of a pre-placed insert, known as Consumable Insert, is used.

“Consumable insert,” is defined in AWS A3.0, “Filler metal that is placed at the joint root before welding and is intended to be completely fused in the joint root to become part of the weld. The consumable insert becomes an integral part of the initial root-weld bead. It ensures complete penetration and smooth tying in of the insert and adjacent pipe, tube or fitting ends. It reduces flow restriction within the bore to a minimum and eliminates root-bead cracking due to notch-effect and abrupt change in cross-sectional weld area. Consumable inserts are made from matching grade welding filler. The Consumable inserts are made conforming to AWS A-5.30 having different cross-sectional profiles.

The common materials used in the Indian nuclear industry are carbon steels (boiler quality grades) and Stainless steels (grade 304). Other grades of materials are also used, but these two are more common. The most common one is Rectangular (Flat) rings for the carbon steel pipes as pre-formed rings and inverted T rings in 16 Mtr. coils for SS pipes. Style A, Coiled Consumable Insert; Style B, Pre-formed rings, Open lap joint; Style C, Pre-formed rings, Open Butt joints; Style D, Solid rings, 4.8 mm rim width; Style E, solid rings, 3.2 mm rim width
## Classes with assembly tolerances are as below:

<table>
<thead>
<tr>
<th>Class 1</th>
<th>Inverted T-shaped Available Styles A; B &amp; C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 2</td>
<td>J-shaped cross-section Available Styles A; B &amp; C styles A:B:C</td>
</tr>
<tr>
<td>Class 4</td>
<td>Y-shaped cross-section Available Styles A; B &amp; C</td>
</tr>
<tr>
<td>Class 3</td>
<td>Rectangular cross-section Available Styles D &amp; E</td>
</tr>
<tr>
<td>Class 5</td>
<td>Rectangular with Contoured Edges Available Styles D &amp; E</td>
</tr>
</tbody>
</table>

### Usage
The insert material is kept sandwiched between the root gaps of two pipes that have accurately machined edges to hold the inserts tightly in place. The root is then fused by GTAW process using underside purging where necessary (like SS joints), either manually or by orbital welding heads. The subsequent filling and capping passes are done by regular filler of the applicable grade. The weld joints pass the standard radiography and high-pressure tests, where needed.

### Typical Applications:
The application for this technology will be varied within the power generation industry. Any application that has tight tolerances on the radial clearance between tubes would be applicable. One of the most important and critical application is with regards with the feeder tubes on CANDU reactors. The feeder tube design imposes stringent welding requirements such as penetration on the repair/replace replacement approaches. In addition to stringent penetration requirements, the feeder tube location and geometry presents challenges for tooling design.

### Editorial Comments:
We, at Weldwell Specialty, have been catering to the Indian Nuclear Industry through manufacture and supply of Consumable Inserts for more than two decades.
Weld Purging in Critical Power Plant Systems

Innovative welding techniques can produce consistently better-quality joints. Proper weld procedures can all help prevent catastrophic failure of safety-critical systems.

Introduction:

Stainless steels are used extensively in the construction of nuclear power plants, primarily for their corrosion resistance. Components and segments include- Core and secondary parts of most reactor types in service today, different types of transport or storage canisters the nuclear decommissioning and waste storage industry, etc. Zirconium and its principal alloy zircalloy, due to their unique physical properties, are widely used in the manufacture of fuel rods especially in pressurised water reactors. Welding, of the above materials, is highly sensitive to contamination by active gases such as oxygen, nitrogen and hydrogen and absorption of which can have a significant effect on mechanical, chemical and thermal properties.

Welding of High-Pressure Steam Pipes and Stainless Steels

The demand for quality in the safety-critical joints during the welding of pipes and tubes in the nuclear industry, is reflected in the stringent regulations laid down in welding procedures. Nevertheless, some welding practices can result in significant effects in both corrosion resistance and mechanical strength. The preferred welding procedures in this type of fabrication are gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW), which offer protection of the exposed upper-fusion zone. The joint around the under bead, however, needs to be protected simultaneously by purging the air that could be in contact with this under bead, known as the root weld, thus protecting the exposed metal by using an inert-gas envelope. Weld purging in these sectors assume an important factor. In addition, weld purging is also sometimes adopted during usage of welding consumable inserts.

Equipment:

The effective welding of exotic metals in nuclear industry, requires the proper tools to create a perfect weld environment. When welding SS, Titanium, Zirconium etc., creating a perfect environment is of utmost importance, because the corrosion resistance depends on it. Successful welding depends on proper purging equipment and techniques. Specially engineered purge products have been designed over the past five years that can withstand the temperatures involved while at the same time maintaining excellent gas-sealing characteristics. They are also rugged enough to survive multiple-use applications. Weld-purging systems are available that can be used at the high temperatures prevailing during pre- and post-heating. Unless strict welding schedules are adhered to, however, not only will discoloration (heat tint) take place, but also corrosion resistance can be significantly reduced.

Weld Trailing Shields®

Two of the most used purging tool used in the nuclear industry are:

To create high-quality welds in the open-shop environment, specially designed and developed flat and radiused Trailing Shields® are available. These shields can be simply attached onto any TIG/GTAW, PAW/Plasma and MIG/GMAW welding torch. As the welding torch is moved forward, the weld remains under an argon gas shield until the welded metal has cooled below its oxidation temperature. This results in a high level of additional inert gas shielding to supplement that supplied by the basic welding torch. Shields are available to match a wide variety of forms from flat to diameters as small as 25 mm. Both internal and external models are available.

Flexible Welding Enclosures®

For welding of small critical components, initially in the nuclear industry, glove boxes, (used to handle radioactive materials) were adapted for welding. To overcome the disadvantage of rigidness and floor-space, flexible enclosures are available at a fraction of the cost. Circular, as well as, rectangular standard enclosures are available, however, sizes can be customised. Argon gas costs are also reduced significantly, and cleaning costs are eliminated.
To meet the higher standards of welding that the Nuclear Industry expects, a unique Weld Purge Monitor® has been designed and developed by Weld Purging Experts Huntingdon Fusion Techniques HFT® that reads all the way from atmospheric level of oxygen (20.94%), down to one part per million (0.0001%), in one instrument. Due to circumstances and lengthy pipelines, it is not practical to measure the oxygen content in the purge gas close to the weld. The PurgEye® 1000 is now available that will display the oxygen level in the welding zone on a Weld Purge Monitor® screen that might be 10, 50 or even 1,000 metres away from the weld. It measures oxygen levels from 1,000 parts per million (ppm), right down to 1 ppm (accurate to 10 ppm), ideal for welding metals such as stainless steels, duplex steels, titanium and zirconium.

**Controlling Purge Gas Quality:**

Control of the oxygen content of the purge gas is crucial to success and a monitor that measures residual oxygen reliably and accurately at the low levels considered necessary when welding zirconium alloys. One of the most important requirement of weld purging is monitoring the purging argon gas quality. The oxygen content in the enveloping gas has to be maintained at optimum safe levels during welding, therefore, appropriate instrument to measure should be selected.

**PurgEye® 1000**

To meet the higher standards of welding that the Nuclear Industry expects, a unique Weld Purge Monitor® has been designed and developed by Weld Purging Experts Huntingdon Fusion Techniques HFT® that reads all the way from atmospheric level of oxygen (20.94%), down to one part per million (0.0001%), in one instrument. Due to circumstances and lengthy pipelines, it is not practical to measure the oxygen content in the purge gas close to the weld. The PurgEye® 1000 is now available that will display the oxygen level in the welding zone on a Weld Purge Monitor® screen that might be 10, 50 or even 1,000 metres away from the weld. It measures oxygen levels from 1,000 parts per million (ppm), right down to 1 ppm (accurate to 10 ppm), ideal for welding metals such as stainless steels, duplex steels, titanium and zirconium.

**Editorial Comments:** The systems and tools described are manufactured by Huntingdon Fusion Techniques, UK and are available in India through Weldwell Speciality, Mumbai
New Product
Kobelco B91 Series Welding Consumables

Introduction
The biggest challenge for thermal power generation is to reduce CO2 emissions and improve efficiency by operating at higher steam temperature and pressure at which fed into power generating turbines. This require special steels such as Grade 91- Cr ferritic steel put into service at thermal power plant boilers worldwide.

Relationship of Mn+Ni content and Ac1
The upper limits for Mn+Ni content has gradually brought down by both standards ASME B31.1 and AWS B9/B91 to Increase the upper limits of the PWHT temperature (760-780°C) essential to exhibit tempered martensite structure for excellent high temperature strength and toughness.

Main feature of Kobelco B91 Series consumables is the addition of cobalt (Co) to clamp Ac1 transformation point (Approx. 800°C) besides limiting Mn+Ni content as per standards. Also, Co addition restrains delta (δ) ferrite formation to have 100% martensite structure and ensure excellent creep resistance. The Electric Power Research Institute (EPRI) proposed an index called Cr-Ni balance (CNB) less than 10% in its report No. 1023199 “Guidelines and Specifications for High-Reliability Fossil Power Plants.”

Larson-Miller Parameter (L.M.P.) in relation to CM-95B91, TG-S90B91 (AWS A5.28 ER90S-B9) and PF-200S/US-90B91 (AWS A5.23 F9PZ-EB91-B91) welding consumables fully satisfy the mechanical property requirements (0.2%PS more than 415MPa and TS is more than 585MPa) even at L.M.P.= 22.0 x 103 equivalent to PWHT parameter of 780°C x 8 hours (i.e. high temperature and extended time) and exhibit better notch toughness at +20°C The CNB equation is:

\[ \text{CNB} = \text{Cr Equivalent} – \text{Ni Equivalent} = (\text{Cr+6Si+4Mo+1.5W+11V+9Ti+12Al}) – (40C+30N+4Ni+2Mn+Cu) < 10\% \text{ (mass\%)} \]

Excellent creep rupture properties
All consumables provide excellent creep rupture properties (dotted line) even at PWHT temperature (780°C) and even under an extended time creep condition of 600°C x 100Mpa.

Conclusion
There are three characteristics of the B91 Series welding consumables. The first is that they correspond to international standards such as ASME and AWS. The second is that high PWHT temperatures can be applied due to their high Ac1 transformation point. And third, they are designed to obtain excellent creep rupture properties even in high PWHT conditions.

Editorial Comment :
For details and availability contact nivek@weldwell.com
Topmost Nuclear Equipment Supplier - Japan is now considered the topmost nuclear equipment supplier. Japan Steel Works, controls 80% of the international market for heavy nuclear forgings, Toshiba largely owns Westinghouse, Hitachi has a global nuclear power alliance with GE, and Mitsubishi Heavy has one with Areva.

International Recognition – Nuclear Power Corporation of India Limited’s prestigious campaign “Atom on Wheels” has won international award under the category of world’s best public communication campaign at the 10th. International event at ATOMEXPO – 2018 held at SACHI, Russia.

Largest Nuclear Power Plant - NPCIL with AREVA S.A is building a 9,900-megawatt (mw) plant at Jaitapur, consisting of six reactors, which upon completion would be the world’s largest nuclear power unit. At present, the agreement is to build the 1st. set of two European Pressurized Reactors, and includes, nuclear fuel supply for 25 years.

Mission Shakti - India conducted, an anti-satellite missile test, as a technological mission by DRDO after the success of anti-satellite weapon (ASAT) test. The test was fully successful and achieved all parameters and it required an extremely high degree of precision and technical capability.

First Fully Welded Bridge – Bogibeel Bridge, the 1st. fully welded bridge, was constructed with adherence to European Codes and Welding Standards. It is Asia’s 2nd Longest Combined Road and Rail Bridge. The low maintenance cost, 4.9 Km. long bridge on the river Brahmaputra connects Assam and Arunachal Pradesh.

Electromagnetic Intelligence Satellite (EMISAT) - ISRO has successfully executed the launch of its first electronic surveillance satellite, EMISAT, aboard the PSLV-C45. The satellite was successfully placed in its intended sun-synchronous polar orbit in April.

Re-structuring of Public-sector Companies – GAIL (India) is to undergo bifurcation into marketing and transportation units. Subsequently, a three-way merger of power generation companies viz. NTPC, SJVN and NHPC.

Consolidation of Indian Steel Industry - In May 2018, Tata Steel took over Bhushan Steel after submitting the highest bid for it in an insolvency auction. The merger would enable Tata Steel to make in-roads to automobile steel industry thereby increasing its presence in the domestic industry.

Prediction & Management of Stress Relaxation Cracking - The Welding Institute (TWI) has recently proposed a robust and validated approach to accurately predict the susceptibility of large scale structures to Stress Relaxation Cracking (SRC) and to determine appropriate heat treatment requirements to mitigate SRC. They are looking for sponsors.

SRC is a failure mode that can occur, over moderate service durations, in stainless steels and nickel alloys, which are essentially solid solution strengthened, but can undergo significant precipitation reactions during elevated temperature exposure. Alloys that are known to have been affected include: 304H, 316H, 347H, Alloy 800/H/HT and Alloy 617. The SRC phenomenon typically occurs in components that have high levels of residual stress and constraint. Although the phenomenon is typically related to in-service relaxation, stress – relief operations after welding or at the first moments of high temperature service, can lead to similar mechanisms of failure, but are typically termed stress-relief cracking or reheat cracking.

First Defense Corridor – To boost indigenous production of defence equipment, the Tamil Nadu Defense Corridor is being set up. Chennai, Hosur, Trichy, Salem and Coimbatore are the nodal cities of this corridor. The idea is to ensure connectivity among various defence industrial units. Several PSUs along with private companies have already committed over Rs. 3,000 crores investment.

World record for continuous operation – NPCIL’s Kaiga 220MW Unit # 1 has created world record of longest continuous run of 962 days on 31-12-2018. The indigenously developed with BHEL supplied nuclear power equipment has had a 99.3% load factor during its run.

WELD INDIA & IC2020 MUMBAI - International Congress IC2020 on "Advanced Welding Technology & Quality Systems for Developing Economies" is planned at the CIDCO Exhibition Centre at Vashi, Navi Mumbai on 6th. To 8th. February 2020. It is being organized by the Indian Institute of Welding (IIW-India) on behalf of the International Institute of Welding. "Young Professionals International Congress 2020 (YPIC2020)” is also being organised as a part of the International Congress. Concurrently welding exhibition "WELD INDIA 2020" is being held from 7th. To 9th. February 2020.