Optimization of Parameters for Welding of Spark Plug Detector

M. Anandaraj[a], P. Parameswaran[b], S. Krishnakumar[a], T. Ezhilarasi[b], V. Thomas Paul[b#], R. Thirumurugesan[b], S. Chandramouli[a], V. Ramakrishnan[a], G. Padmakumar[a], Shaju K Albert[b], B. K. Nashine[a] ,V. Prakash[a], P. Selvaraj[a]

[a]Fast Reactor Technology Group, [b]Metallurgy & Materials Group
Indira Gandhi Centre for Atomic Research, Kalpakkam, India - 603 102
Corresponding author, Email: vtp@igcar.gov.in

DOI : 10.22486/iwj.v53i1.191279

ABSTRACT

One of the spark plug leak detectors employed in high temperature liquid sodium systems had failed to detect a sodium leak and systematic failure analysis was carried out to identify the root cause of the failure. Radiography image of the leak port nozzle revealed that the extension wire which was welded with spark plug electrode had snapped. Since the failure originated from the cracks present in the weld, it was decided to standardize the welding procedure of spark plug electrode to extension wire to prevent the possibility of similar failures in future. Three different materials viz, stainless steel, nickel, inconel were chosen as extension wires as well as filler wires to optimize the welding parameters. Microstructural studies in terms of presence of defects, interface integrity between the weld and extension wire as well as that of spark plug electrode were carried out. Based on this, the final choice of welding parameters, material for extension wire and for filler wire to achieve a sound weld was proposed.

Key words: Spark plug detector; extension wire; failure analysis; metallography; welding procedure qualification.

1.0 INTRODUCTION

Liquid sodium is used as coolant in Fast Breeder Reactors. Sodium readily reacts with air and the standard valves used in the water systems cannot be used for sodium systems. Alternatively bellows sealed valves in which the bellows act as primary leak tight barrier are very much suitable for sodium service. These valves are used for flow control, isolation and for emergency dumping. Leak ports form a part of this valve and indigenously developed spark plug type leak detector is introduced in the port to detect any sodium leak during the incipient stage itself. These detectors work on the principle of electrical conductivity. Whenever the bellow fails, liquid sodium enters the leak port and touches the extension wire welded to the spark plug thus providing a short circuit path in the electric circuit. This would trigger an alarm indicating that a leakage has happened.

One of the spark plug detectors had failed to detect a leak and created a critical situation in the control room. The failed detector was taken up for the failure analysis and on scrutiny of the detector; it was observed that the central electrode of the spark plug has snapped from the extension wire which is basically a sensing stainless steel wire. Extensive failure analysis was carried out on the failed weld region to identify the failure mode of the snapped extension wire. Weldments in any component can fail either at weld or heat affected zone (HAZ). As far as stainless steel is concerned, solidification cracking or hot cracking in the weld can occur or alternatively stainless steel weld can fail at HAZ during service endurance due to well-known sensitization problem [1]. Since the present case does not involve any mechanical loading, it was presumed that failure would have occurred due to pre existing defects in the weld region or possible corrosive action generated by hot caustic environment.

To prevent the possibility of similar failures in future it was recommended to standardize the welding procedure of extension wire to spark plug electrode. Welds of different combinations of extension wires with filler wire with spark plug were carried out and subsequent metallographic examination also carried out to qualify the welding parameters. This paper brings out the failure analysis of the snapped detector and further a systematic experimentation on the weld procedure carried out for welding of spark plug electrode with extension wire to achieve a sound weld.

2.0 DETAILS OF SPARK PLUG

A spark plug consists of a center electrode, an insulator, a metal casing or shell, and a side electrode (also called a ground electrode). The central electrode is made of Ni-Cr alloy. It is welded to SS316 extension wire by TIG welding using SS316 filler wire of suitable size. The spark plug is normally a part of an electrical circuit. It is screwed in a small pocket in the valve. If the liquid sodium collects in this pocket it causes electrical short between its installed central conductor and the body. The temperature seen by the weld area is around 200°C. The spark plug will be normally in air/moisture atmosphere inside the port. In case of a bellows failure, sodium at the maximum possible temperature [~550°C] will come in contact with the extending wire and the spark plug central electrode. **Fig. 1** depicts the conventional spark plug converted into detector by welding an extension wire after side electrode of spark plug is removed.

3.0 FAILURE ANALYSIS

Fig. 2 gives the radiography of the snapped wire. Since there is no mechanical load involved, the exposure to high temperature or corrosive environment is likely to be a possible cause of the failure. Further the failed region is located in the weld joint [**Fig. 3**] which suggests the role of joining and its effect on the initiation of a failure. It is decided to identify the failure mode of the snapped wire in particular at the weld joint. Therefore careful study on the failed piece was carried out. Systematic fractography of the failed joint has been carried out using Scanning Electron Microscopy (SEM) and chemistry of the wires was confirmed through Energy Dispersive X-Ray Spectroscopy (EDS) in SEM. **Fig. 4** shows the microstructure of the weld region. A few cracks [**Fig. 4-b**] were observed in the weld region. Further, microstructure consisting of dendrites in two different ortrhogonal direction were observed **Fig.4d** shows the nature of grains in the interfacial area which suggests corrosion attack as the grains have flaked out. Presence of dendrites in orthogonal direction suggests possible elemental segregation [2]. In order to examine on the elemental distribution across weld interface, EDS line scan spectra were gathered from representative regions. It can be observed from **Fig. 5** that the presence of oxygen, Cr and Fe vary distinctly suggesting the proneness to corrosion attack and oxidation during service. The operational log suggests the possibility of sodium ingress causing corrosive atmosphere around weld area. In order to confirm if the crack originated at the weld or at the interface, longitudinal section of the failed piece was prepared through conventional metallographic procedures.

Fig. 6 shows the micrographs representing the section. It can be observed that the crack has originated from the weld region that formed between Ni base alloy and stainless steel and propagated intergranularily through the dendritic region. Hardness profile across the weldment was carefully assessed and is shown in **Fig. 7** as a schematic of the section with the representative hardness values

It can be observed that the hardness is quite varied in nature which can be understood considering the presence of dendrites of varying sizes in the weldment [2]. Further, the solidification cracks originated following cooling after welding can propagate easily across the soft zones present between hard zones during service life.

Based on above metallographic studies, the following points are summarised:

- The extension wire has snapped resulting in non-performance of the detector. A few cracks from solidification of weld were observed in the weld. An initial leak from the cracks is likely root cause of the failure.
- Presence of oxides of Na suggests that the small amount of sodium that has leaked out has converted into oxide and further into alkali in the presence of moisture at high temperature. This could have attacked the area which is chemically prone, in particular the weld interface area.

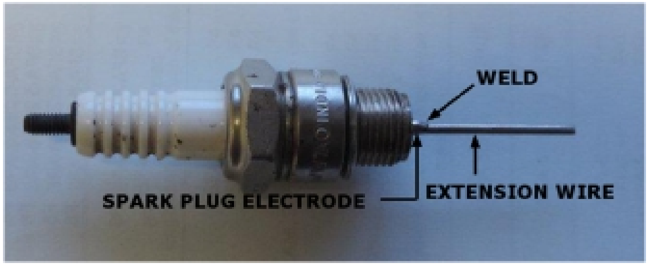

Fig.1 : Spark plug type Leak detector

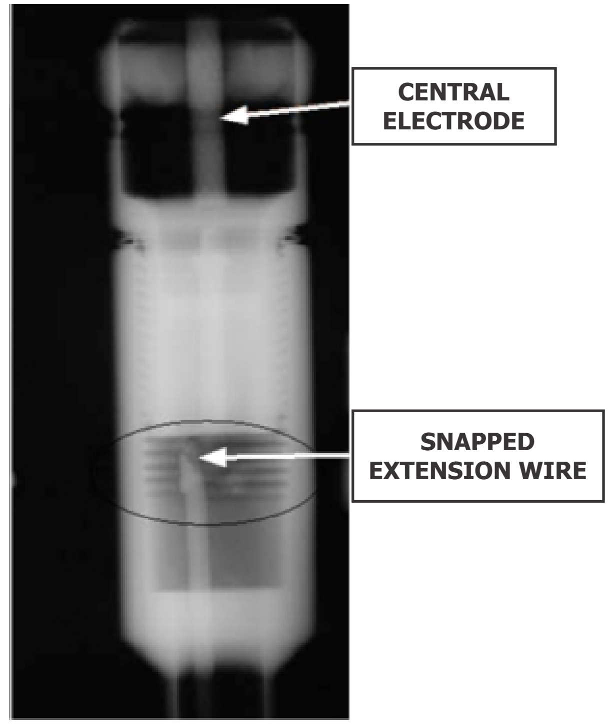

Fig.2 : Radiography image of snapped extension wire

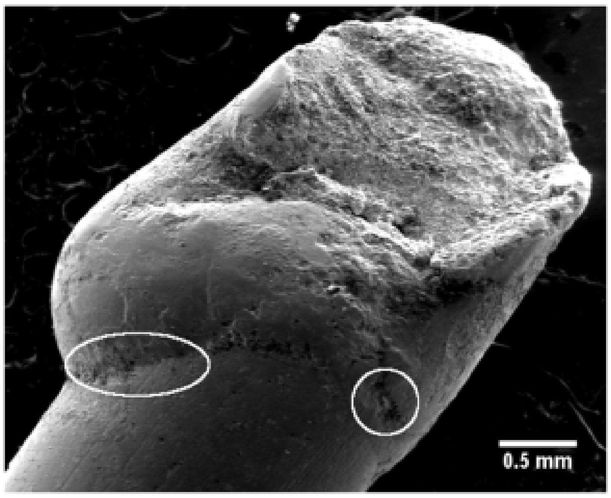

Fig.3 : Spark Plug wire-failed end with the weld region encircled

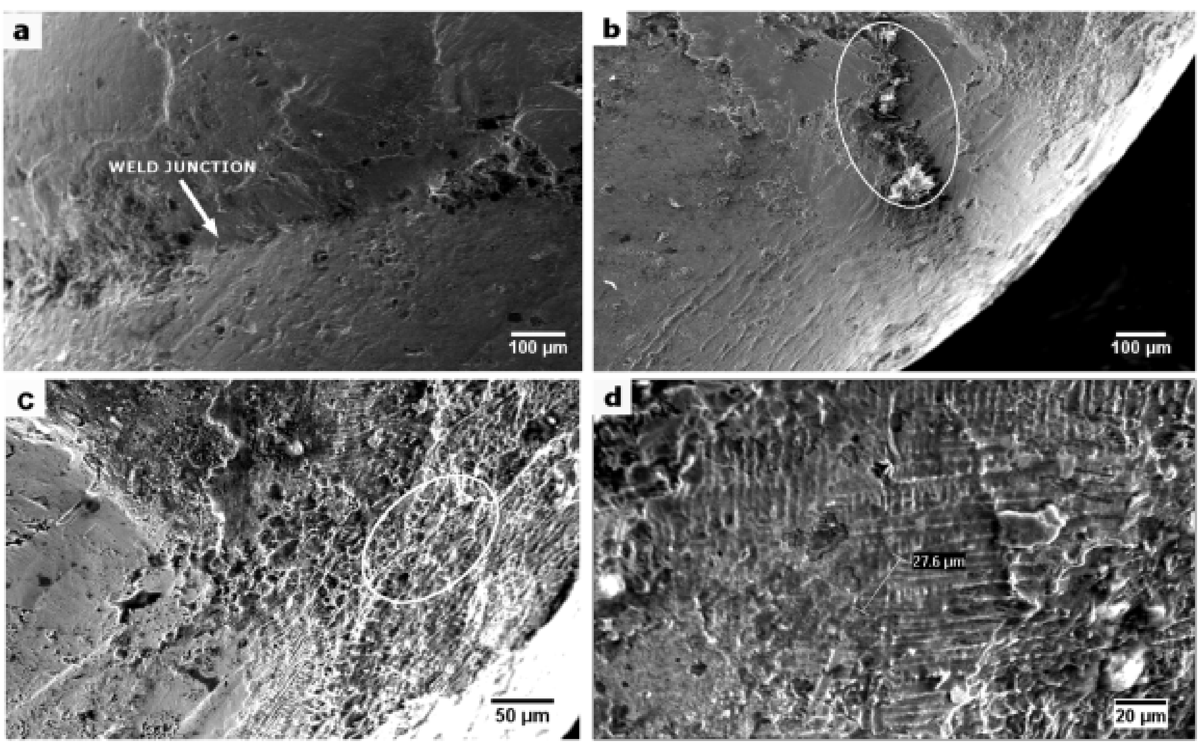

Fig.4. SEM image of (a) weld interface with micro porosities (b) micro cracks carrying white debris of Na_2O (c) dendritic microstructure in weld close to interface and (d) magnified view showing orthogonal dendrites

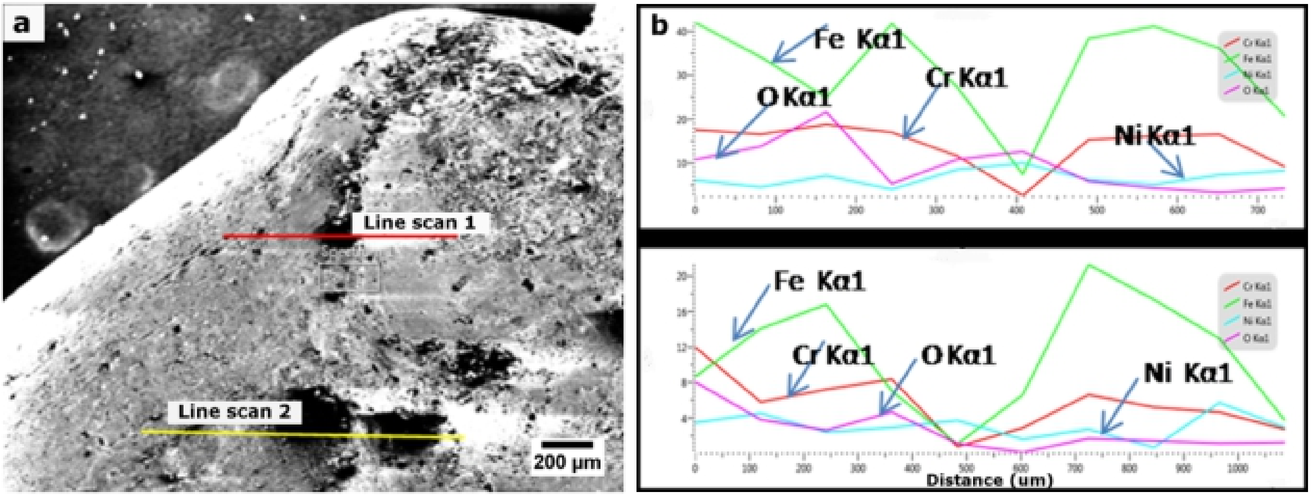

Fig.5. (a) weld Interface area; region of line EDS marked as line scan 1 & line scan 2; (b) spectrum acquired through scan 1 (above) & scan 2 (below) indicating the segregation of (Cr, Fe, Ni & O) elements seen at the interfacial area

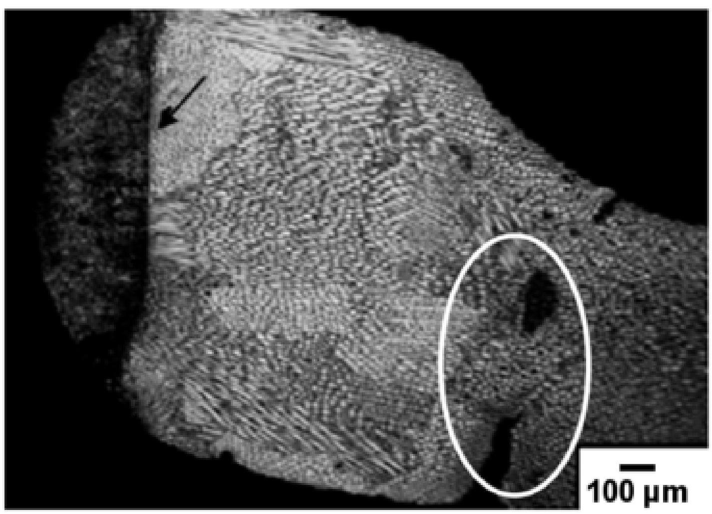

Fig.6 : Crack seen in weld (marked by a round); arrow marks interface with Ni spark plug wire

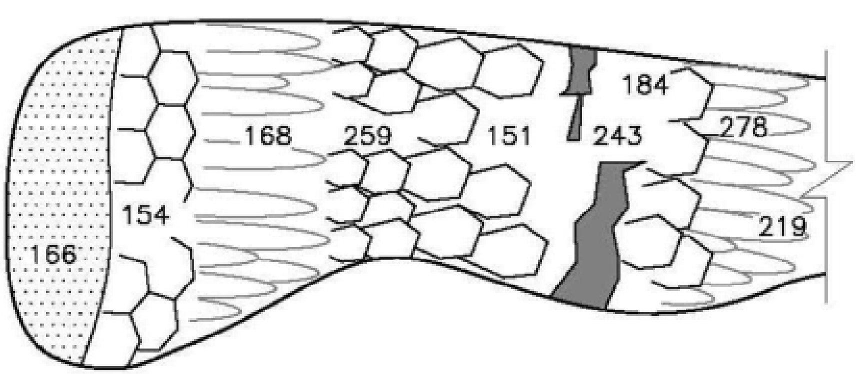

Fig.7 : Schematic figure with hardness marked on different regions; note that hardness around cracked region varies on either side distinctly

- Exposure to high temperature and corrosive atmosphere resulted in flaking of grains as observed in the regions around the weld.
- It is recommended that a systematic study of welding process of spark plug central electrode with stainless steel extension wire be taken up to optimize the conditions for a sound weld with (i) less chemical inhomogeneity, (ii) uniform hardness across the weldment (iii) uniform microstructure (iv) no microcracks and (v) no blow holes. Further accelerated corrosion tests can be carried out to ascertain the life.

4.0 WELDING OF SPARK PLUG

Gas Tungsten Arc Welding (GTAW) process was carried out to weld the spark plug electrode (2 mm diameter) with extension wire (1.5 mm diameter). **Fig. 1** shows the spark plug welded with extension wire. Special fixture was fabricated to hold the spark plug and extension wire in line and welding was completed within few seconds. It was recommended to use filler wires of smaller diameter to reduce the size of the filler material deposit at the weld joint as it may otherwise lead to stress concentration at the weld joint. During the welding process, it was also recommended to increase the Ar gas purging flow rate (from 1lit/min to 3 lit/min) to reduce oxidation of the weld metal.

Based on the above recommendations, different combinations of extension wire with filler wire (**Table 1**) were considered for welding. Metallography results are shown in **Fig.8 (a-e)**. It can be observed that among the five different combination of filler and extension wire, presence of non uniform microstructure around the interface (encircled) dominates in case (a), (c) and (e) and though the microstructure was almost uniform in (d), several blow holes (shown by arrows) were observed.

Nonuniformity in microstructural features occurs if the alloying elements segregate at the boundaries. Since the duration of welding process was few seconds, the diffusion of elements is precluded and hence the heat affected zone exhibits a complex microstructure with associated hardness variation in the region. Porosity or blow holes in Ni and Ni –Cu alloys is reported [3, 4] when atmospheric gas contamination occurs during welding. Even though the studies have employed higher Ar gas purging, it is found inadequate to prevent the contamination in (d) which could have resulted in porosity.

In case of (b), the microstructure was found to be homogeneous and the hardness across the interface was found to be uniform as well. Based on the above results it was recommended to employ inconel filler wire for welding of Ni extension wire to the spark plug. This also matches with an earlier reported similar study on welding of 316LN stainless steel with alloy 800 [5]. While thermal expansion coefficient of inconel and nickel are found to be similar, thermal conductivity of nickel is five times better than inconel, weldments cools linearly by releasing heat to nickel wire, and hence the weld joint appears to be good [6].

Table 1: Different combinations of welding of extension wire and filler wire and their micro structural observation

Extension Wire material	Extension on wire size	Filler wire	Filler wire size	Current	Figure reference	Remarks
316L	1.5 mm	Inconel	0.8 mm	20 A	Fig. 8a	Microstructure not uniform in the welds.
Nickel	1.5 mm	Inconel	0.8 mm	20 A	Fig. 8b	Uniform micro structure and uniform hardness value at the weld interface (circled region). So accepted.
Inconel	1.5 mm	Inconel	0.8 mm	20 A	Fig. 8c	Microstructural integrity affected in Inconel - Inconel weld.
Nickel	1.5 mm	Nickel	0.8 mm	20 A	Fig. 8d	Microstructure uniform but blowholes observed.
316L	1.5 mm	316L	0.8 mm	15 A	Fig. 8e	Microstructure not uniform. Microcracks seen weld metal

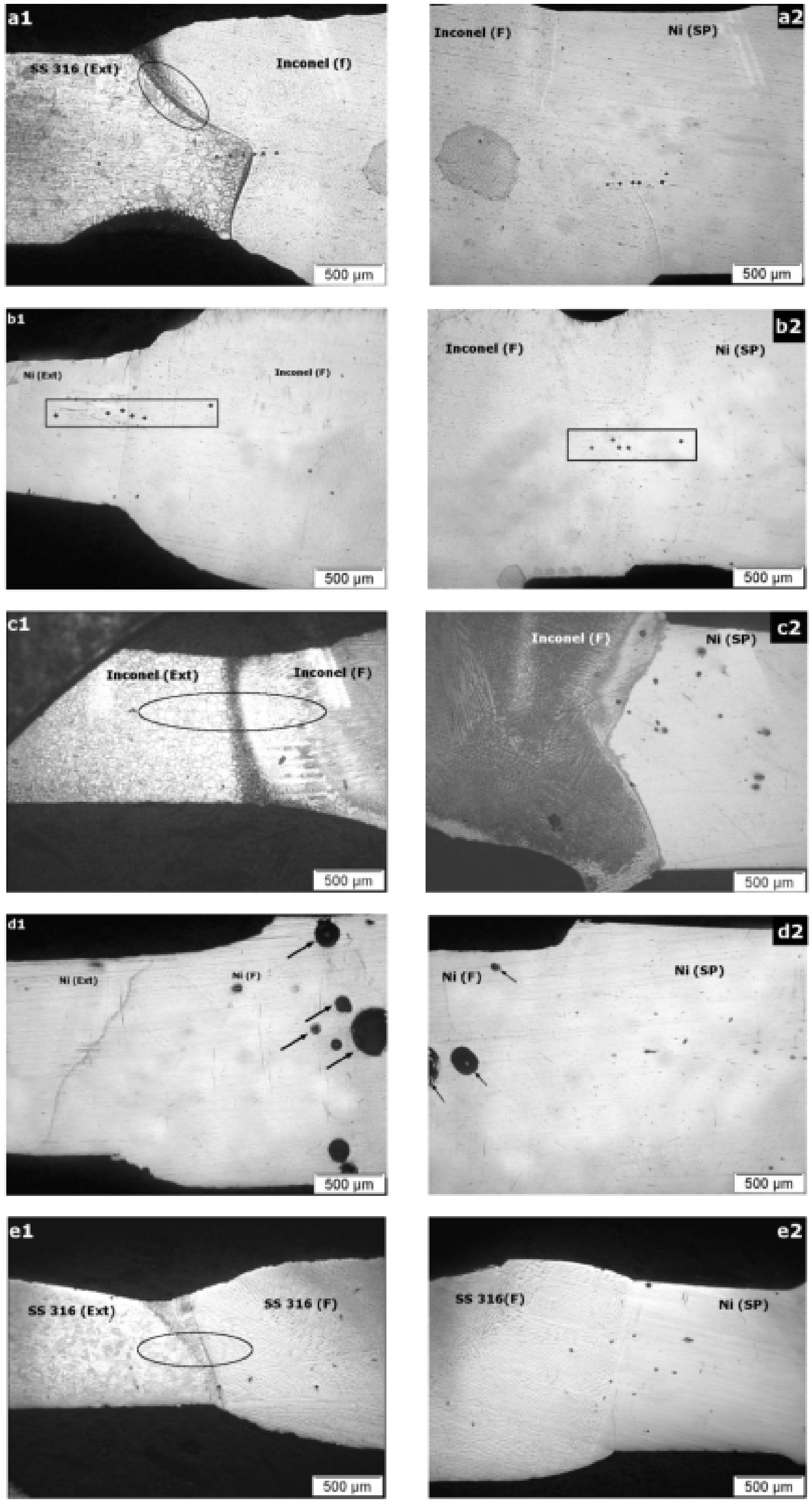

Fig.8 : (a-e) microstructure at the weld interface of different combinations of extension wire and filler wire (left (a1 to e1) – interface of extension wire with filler wire; right (a2 to e2) -interface of spark plug with filler wire); arrows mark blowholes; non uniform structure rounded; hardness marks in (b) shown in round suggests uniformity in hardness; cracks seen in weld metal in (e)

5.0 CONCLUSIONS

- Failure analysis of failed Spark plug detector was carried out through a systematic metallographic analysis. The studies indicated the formation of dendrites of orthogonal orientation and presence of micro chemical segregation. Hardness measurement confirmed the variation in the region of weld. This is suspected as the cause of micro cracks that were generated when the welds solidified.
- To achieve a sound weld between spark plug and the stainless steel extension wire, systematic experimentation of the welding procedure was carried out by choosing different extension wire material.

Based on the results obtained from metallographic and micro hardness studies conducted on the cross sections of the different welds the recommended inconel filler wire is employed for welding of nickel extension wire to the spark plug. Accordingly welding procedure was derived to qualify the spark plug welding. This welding procedure (WPS) was adopted for all the bellows sealed valves in new experimental sodium loops.

REFERENCES

[1] Chaudhari R, Parekh R and Ingle A (2014); Reliability of dissimilar metal joints using fusion welding, Int Conf on Machine Learning and Mechanical Engineering (ICMLEME'2014), Dubai, UAE.

[2] Kaya H, Cadırlı E, Boyuk U and Maras N (2008); Variation of microindentation hardness with solidification and microstructure parameters in the aluminium based alloys, Applied Surface Science, 255, p. 3071.

[3] https://www.nickelinstitute.org/~/Media/Files/Technical Literature/Copper_Nickel Alloys Properties and Applications_12007_.pdf

[4] Ramirez JE, Han B and Liu S (1994); Effect of welding variables and solidification substructure on weld metal porosity, Metal and Mat Trans A, 25, p. 2285.

[5] Sireesha M, Albert SK, Shankar V and Sundaresan S (2000); A comparative evaluation of welding consumables for dissimilar welds between 316LN austenitic stainless steel and alloy 800, Materials Science and Engineering A, 292, p. 74.

[6] Hidnert P (1957); Thermal expansion of some nickel alloys, Journal of Research of the National Bureau of Standards, 58.