2017 International Nuclear Atlantic Conference - INAC 2017
Belo Horizonte, MG, Brazil, October 22-27, 2017
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR – ABEN

Agência Brasileira do ISBN
ISBN 978-85-99141-07-6

RECENT ADVANCES ON CHARPY SPECIMEN RECONSTITUTION TECHNIQUES

Arnaldo H. P. Andrade[1], Raquel M. Lobo[1] and Carlos Alexandre J. Miranda[1]

[1] Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN - SP)
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP
aandrade@ipen.br

ABSTRACT

Charpy specimen reconstitution is widely used around the world as a tool to enhance or supplement surveillance programs of nuclear reactor pressure vessels. The reconstitution technique consists in the incorporation of a small piece from a previously tested specimen into a compound specimen, allowing to increase the number of tests. This is especially important if the available materials is restricted and fracture mechanics parameter have to be determined. The reconstitution technique must fulfill some demands, among them tests results like the original standard specimens and the loaded material of the insert must not be influenced by the welding and machining procedure. It is known that reconstitution of Charpy specimens may affect the impact energy in a consequence of the constraint of plastic deformation by the hardened weldment and HAZ. This paper reviews some recent advances of the reconstitution technique and its applications.

1. INTRODUCTION

Neutron irradiation degrades the mechanical properties of reactor pressure vessel (RPV) steels. The extent of the degradation is governed by many factors such as neutron fluence, neutron energy, irradiation temperature, neutron flux and the concentration of deleterious elements in the steel. A RPV operational life of 60 years is being considered frequently by many utilities in their plant life management (PLIM) programs, and even 80 years is mentioned often in the life extension plans of USA reactors. Guidelines are needed to treat long term irradiation effects within the ageing management plans of nuclear power plants (NPP), for monitoring radiation embrittlement during life extension periods since the standard RPV surveillance programs were designed only to cover a period of 40 years [1].

When plant life extension (PLEX) is required, additional surveillance data are also required, to improve the definition of the embrittlement trend curve (ETC) at the higher neutron fluence levels anticipated. Frequently, however, there is insufficient unirradiated material available to machine additional surveillance specimens for exposure to irradiation for monitoring material degradation during life extension. In order to avoid the high costs and burden of long-term storage of irradiated materials, some plants may wish to discard broken Charpy specimens and other surveillance materials remaining from surveillance test programs conducted years ago. However, broken Charpy specimens, particularly those from reactor vessels having radiation sensitive materials, may provide useful information (such as specific materials embrittlement data), and should be stored in appropriate ways and places to avoid oxidation and permit easy retrieval for life extension studies [1].

The initial design lifetime of the nuclear reactor pressure vessels was based on mechanical conditions such as operating pressure and temperature. Now, it is well known that we must add mechanical degradation due to in-service irradiation. This degradation is caused by the interactions of neutrons with the atoms of the material that makes up the vessel's steel structure. The neutron bombardment leads to defects in the crystalline lattice such as vacancies, interstitial atoms, and solutes. Over time these defects form clusters at the nanometric level or develop into dislocations. This causes hardening of the material resulting in possible fracturing due to cleavage. The foregoing can be summarized as a loss of the steel's properties, specifically its fracture toughness [2]
.

Charpy mechanical testing is an important part of the nuclear surveillance program that qualifies reactor pressure vessel embrittlement due to irradiation (Fig. 1) [3].

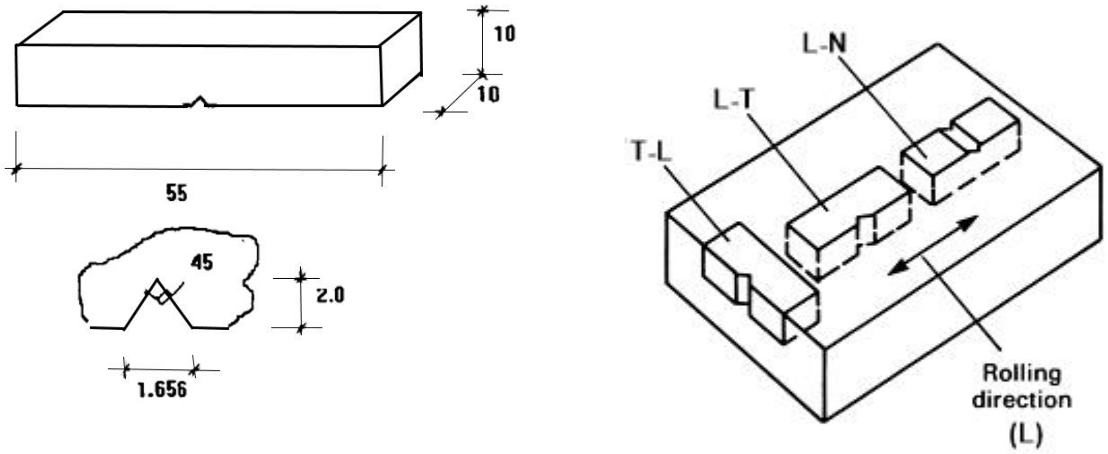

Figure 1: Charpy V specimen geometry (in mm) and orientation [3]

The technique of constructing specimens from small quantities of materials is commonly called "reconstitution". Reconstitution techniques are often used to allow material from previously fractured Charpy-V specimens to be reused for additional experiments. The two halves of a fractured specimen are machined to remove the deformed material. End tabs are then welded to non-deformed material, to become the central part of a three-element bar to be used for a new test, as shown in Figure 1. The process must not alter the material near the notch, so that the reconstituted sample has the same impact behavior as the parent material [4].

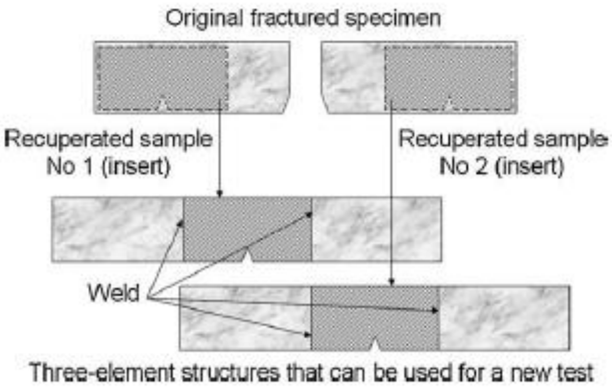

Figure 1: Charpy reconstitution principle [4].

Although the length of the specimen insert is required not less than 18 mm in ASTM E1253 which is the technical standard to reconstitute Charpy specimens, the minimum length of the specimen insert required should be 10 mm when L-T direction Charpy specimens that have been applied to the early domestic nuclear power plants are reconstituted into T-L direction specimens to test the upper shelf absorbed energy of T-L direction specimens. The length of the specimen inserts to preserve the absorbed energy of the Charpy specimen is correlated to the absorbed energy of its material. The significant part of upper shelf energy is attributed to the energy for the plastic deformation zone near V-notch in the Charpy specimen. To preserve the absorbed energy, the anticipated plastically deformed zone shall not be affected by the reconstitution procedure. [5]

2. THE ARC STUD WELDING PROCESS (ASW)

The term “stud welding” is used in general for joining a metallic end tab to another similar metallic piece. Welding may be by electric arc, resistance, friction, laser ray, electron beam, or other processes, with or without inert shielding gas. The equipment used by Romero et al [2] (Figure 2) is an electric arc welding unit with compression, with high purity helium as the inert shielding gas.

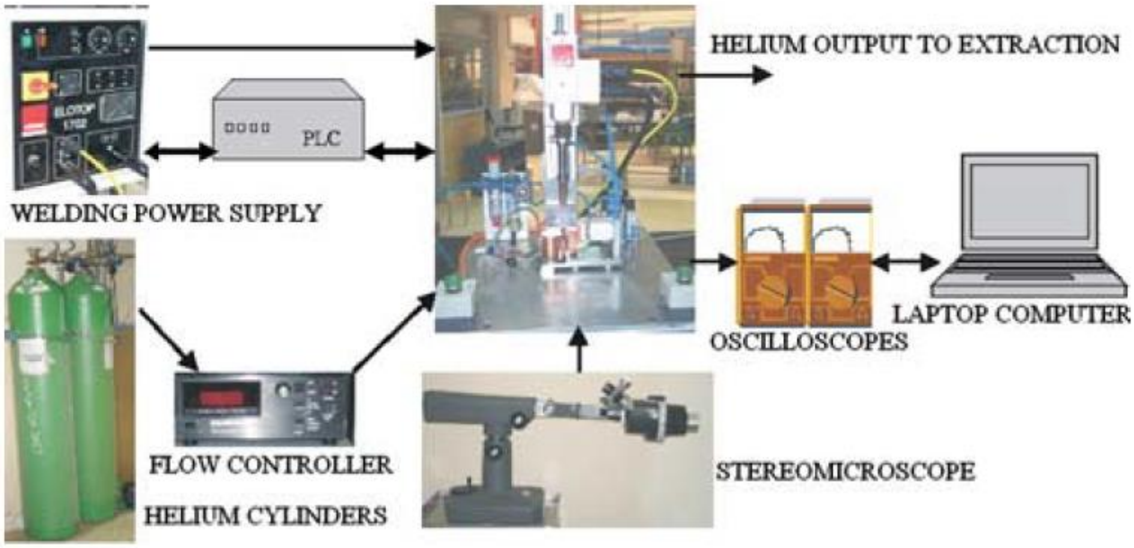

Figure 1: Welding system diagram [2].

For the welding process of irradiated inserts, the following specific requirements and particularities need to be considered:
1. Radiological Protection and Safety. The material is activated and emits around 100 mR/h of gamma rays per specimen. Therefore, suitable measures must be taken to assure proper protection of personnel during handling, welding, and machining.
2. The properties of the material must not be altered. When welding end tabs to the insert, the heat input can cause local annealing and alter the mechanical properties to be tested. This imposes the limitation that the weld must be as thin as possible, with a small heat-affected zone (HAZ).
3. Qualification of the process. The stud welding process must be in accordance with ASTM Standard Designation: E 1253-07 “Standard Guide for Reconstitution of Irradiated Charpy-Sized Specimens” [6].
4. Quality Assurance Program. In this process, it is used a quality assurance program compatible with the 18 criteria established in the Code of Federal Regulations 10CFR50, Appendix B.

2.1. Weld quality in a reconstitution process

Bourdiliau et al [4] evaluated the feasibility of different reconstitution techniques for use in a hot cell. The following experimental techniques were investigated: arc stud welding, laser welding (LW), and friction welding. An ideal reconstitution process provides welds of a good quality from a metallographic point of view, and identical impact behavior when compared to the reference specimens. A narrow heat-affected zone (HAZ) and fusion zone (FZ) is also important because, if the plastic zone due to the Charpy impact extends in the HAZ, lower resilience values are observed. The plastic zone typically extends from 3 mm for a low temperature test [7] to 9 mm at high temperatures from each notch side [8]. In addition, the reconstitution process must be adaptable to a hot cell and managed according to the ASTM E 1253 Standard.

Arc stud welding (ASW) is currently the most common welding process for reconstitution because of its adaptability to a nuclear environment and its low cost [2] An arc is initiated between the end tab (also called stud), and the insert, melting the surface of both pieces. Then the end tab is forced onto the insert and the materials fuse, completing the weld. Cylindrical end tabs are generally used to ensure proper alignment of the three blocks, requiring some machining. SW and electron beam welding (EBW) are currently the techniques used in hot cells. SW is also a successfully used technique for the reconstitution of subsize Charpy specimens. Moreover, SW is a convenient process to reconstitute non-irradiated and irradiated Charpy pre-cracked specimens with a 10mm insert length, which are tested in 3 point-bending [9]. These specimens are tested to obtain indirect fracture toughness values, instead of testing standard CT specimens.

EBW shows the advantage of a narrow HAZ, thus making it possible to use short inserts [10]. Contrary to the SW, 10x10 mm^2 end tabs may be used because this process is not plagued by alignment problems. However, it is the most expensive technique (along with LW) and the need to work under vacuum makes it difficult to adapt this process in a hot cell.

Reconstitution methods using laser welding (LW) have also been done. The advantages are the same as EBW: narrow HAZ and utilization of 10x10 mm^2 end tabs. However, this process is also expensive [11]. Friction welding (FW) has also been used to reconstitute non-irradiated RPV steels Charpy-V specimens [12]. The process advantages are a low HAZ and the absence of FZ, but the equipment is quite expensive and complex to install in a hot cell.

ASW is today the most successful technique because of its many advantages. Indeed, besides the fact the Charpy tests of the reconstituted specimens are consistent with the reference specimens, the low cost of the device and its small footprint facilitate the installation in a hot cell. Furthermore, this equipment is marketed by laboratories and may be purchased as a standard nuclearized version. This process is preferred for a quick installation and can be almost immediately operational.

3. CONCLUSIONS

Arc stud welding (ASW) can be successful applied for the reconstitution of Charpy V (10x10x55 mm) test specimens with size of the insert 10x10x10 mm.

REFERENCES

1. A. Ballesteros, E. Altstadt, F. Gillemot, H. Hein, J. Wagemans, J. Rouden, J. Barhhelmes, K.Wilford, M. Serrano, M. Brumovsky, R. Chaouadi, S. Ortner, "Monitoring radiation embrittlement during life extension periods", *Nuclear Engineering and Design* **267** pp. 197-206 (2014)
2. J. Romero, R. Hernandez, F. Fernandez, F. Mercado, E. Van Walle, "Reconstitution Process by stud Welding for the Surveillance Program in Mexico", *Journal of Testing and Evaluation* **35,** pp. 514-521 (2007)
3. A.H.P. Andrade, C.A.J.Miranda, C.T.E. Aquino, J.R.B. Cruz, " Análise Térmica de Corpos de Prova de Impacto tipo Charpy com Entalhe em V", *5º Congresso Geral de Energia Nuclear* Rio de Janeiro, Proceedings pp. 431-436 (1994)

4. B. Bourdiliau, G. M. Decroix, X. Averty, P. Wident, Y. Bienvenu “Comparative study on Charpy specimen reconstitution techniques” *Nuclear Engineering and Design*, **241**, pp.2722-2731 (2011).
5. Y. Atago, T. Osaki, “Reconstitution technology of Charpy surveillance specimens with short insert length”, *ICONE-11: 11 international conference on nuclear engineering,* Tokyo (Japan); 20-23 Apr 2003; CD-ROM Track Nº 02, Session 2-3, ICONE-36201 (2003)
6. ASTM Standard E 1253-07, 2007. Standard Guide for Reconstitution of Irradiated Charpy-Sized Specimens. 2007 Annual book of ASTM Standards. Section 12: Nuclear energy (II), Solar and Geothermal Energy, vol. 12.02, pp. 634-637.
7. E. Van Walle, April 2000 *RESQUE: Reconstitution Techniques Qualification & Evaluation to study Ageing Phenomena of Nuclear Pressure Vessel Materials.* Recommendations for Reconstitution of Non-irradiated and Irradiated Charpy-size Specimens. Commission of the European communities’ report. SCK-CEN Mol, Belgium, R-3450
8. E. Keim, R. Langer, E. Van Walle, M. Scibetta, M.J. Valo, H. -W. Viehrig, H. Richter, T. Atkins, M. R. Woorton, L. Debarberis, M. Horsten, 2002 *RESQUE: determination of the lowest acceptable insert length for reconstituted C_v – impact and pre-cracked C_v specimens.* In: M. A. Sokolov, J. D. Landes, G.E. Lucas, (Eds), Small Specimen Test Techniques. Fourth Volume. ASTMSTP 1418. ASTM International, West Conshohocken, PA, pp. 426-437.
9. D. Ferreño, M. Scibetta, I. Gorrochategui, R. Lacalle, E. Van Walle, F. Gutiérrez-Solana, “Validation and application of the Master Curve and reconstitution techniques to a Spanish nuclear vessel”. *Engineering Fracture Mechanics* 76, pp. 2495-2511 (2009)
10. I. Yankova, B. Tabakova, Electron beam welding reconstitution technology of Charpy-V specimens. In: *Proceedings of the International Conference on Nuclear Energy for New Europe* 2005. Bled Slovenia, September 5-8.
11. M.P Manahan Sr., J. Williams, R.P. Martukanitz, Laser weld reconstitution of conventional Charpy and miniaturized notch test (MNT) specimens. In: W.R. Corwin, F.M. Haggag, W.I. Server (Eds.), *Small specimen Test Techniques Applied to Nuclear Reactor Vessel Thermal Annealing and Plant Life Extension.* ASTM STP 1204 (1993) ASTM, Philadelphia, PA, pp. 62-76.
12. K. Onizawa, K. Fukaya, Y. Nishiyama, M. Suzuki, S. Kaihara, T. Nakamura, Development of a reconstitution technique for Charpy impact specimens by surface-activated joining for reactor pressure vessel surveillance. *International Journal of Pressure Vessel and Piping* **70,** 201-207 (1997)