

WENRA

Recommendation in
connection with macro-
segregation anomalies found
in French reactors.

01

Background

01.1 The findings in France

In late 2014, mechanical tests performed on a Reactor Pressure Vessel (RPV) closure head representative of that of the Flamanville EPR (FLA3) revealed the presence of a high carbon concentration in the central top part, leading to lower than expected fracture toughness values.

The first measurements on the RPV closure head and bottom head already installed in FLA3 reactor confirmed the presence of this anomaly. The detection of this anomaly led ASN to ask AREVA NP and EDF to learn all possible lessons from this event.

The analyses carried out by EDF since 2015 on operating reactors concluded that certain steam generator (SG) channel heads, manufactured by Areva Creusot Forge (ACF) and Japan Casting and Forging Corporation (JCFC) obviously had areas having high carbon content.

It is important to stress that those technical anomalies do not represent counterfeiting, fraudulent or suspect items (CFSI) identical to those stemming from ACF workshop.

01.2 Metallurgical considerations

Positive (negative) macro-segregation in an ingot refers to variations of the content of alloying elements above below the nominal alloy composition over large length scales. A specific case is carbon macro-segregation. Carbon macro-segregation only affects a limited volume of the ingot: positive carbon macro-segregation is found at the top part of the ingot while negative macro-segregation appears at the bottom. Carbon macro-segregation occurs during the manufacturing of the ingot and its level depends on the ingot pouring method, the type and weight of the ingot, and the cooling method.

Carbon macro-segregation cannot be mitigated through processing of the ingot after solidification is complete and its level can only be reduced by removal of the most affected zones. Excessive residual positive carbon macro-segregation is due to an insufficient discard of the top part of the ingot and insufficient machining during the manufacturing process.

As carbon is increased, resistance to fracture (toughness) is decreased in the residual positive carbon macro-segregation and can therefore have an impact -such as a risk of breach- on the structural integrity of large forged pressurized components during operation.

In conclusion, large forgings are most prone to heterogeneities in the chemical composition. But the macro-segregation in an ingot can be avoided or limited to an acceptable level by discarding and machining.

01.3 The role of inspections and of the material qualification

The acceptance tests of a component generally include compositional checks at specific locations corresponding to the ingot bottom and top, mechanical tests at the same locations and non-

destructive testing (NDT) of the whole volume of the forged part to detect the presence of unacceptable flaws.

However, for some components made from forged plates, it may happen that the test specimens for chemical content check are not performed on locations corresponding to the ingot top and/or bottom. Performing acceptance tests at adequate locations depending on the type of Ingot and manufacturing process of the component is therefore considered the most important step to assure that the component is free of excessive carbon macro-segregation.

However, in addition to these tests, it can be necessary to carry out qualifications of the material on scale-one replicas or representative materials in order to prove the removal of positive macro-segregation in the semi-finished products. The role of the material qualification for a new manufacturing process by performing non-destructive and destructive tests in specific zones close to expected areas of positive macro-segregation is very important.

02

Recommendations to WENRA members

2.1 WENRA recommends to WENRA members to perform investigations on the issue of excessive residual positive carbon macro-segregation in large low-alloy steel forgings based on the following two-step verification of materials quality and structural integrity of the components as described below:

Step 1: Review by the licensees, on request of the safety authorities, of components which may be affected by macro-segregation.

Step 2: Evaluation of the results of the review by the national safety authorities.

In cases where some components are concerned by a risk of excessive residual positive carbon macro-segregation that threatens to undermine their structural integrity, the national nuclear safety authorities should request the licensees to justify the structural integrity of those components and should examine this justification and carry out the appropriate actions.

2.2 WENRA members are asked to reinforce their supervision activities to verify on a regular basis the implementation of the recommendations to the licensees in paragraph 03 (recommendations to the licensees) of this document.

03

Recommendations to the licensees

WENRA recommends, through WENRA Members, to disseminate the following guidance to the licensees such as:

- 1) The licensee is responsible for ensuring that adequate means are developed for keeping manufacturing data and records, archive materials and experience feedback concerning design and manufacturing, both internally and at the designers and manufacturers levels. Attention shall be paid to this when selecting and making agreements with the designers and manufacturers of components.
- 2) For reactors and equipment under design or under construction, the licensee should ensure that the technical qualification of the manufacturing process integrates thorough understanding, available knowledge (extending to all industries) and potential technical issues.

In order to do so, the licensee should at least ensure that manufacturing parameters, that materially affect nuclear safety, are identified, controlled and monitored, in order to ensure the expected quality of the components (e.g. Evaluation of the risk of heterogeneity, location of test coupons, thermal treatment, forging stages, non-destructive testing).

All parties involved in design and manufacturing should develop adequate means for keeping the knowledge, related to safety.

- 3) The relation between the licensee, designers and manufacturers should be reinforced, in particular regarding any potential manufacturing issue that affects safety (e.g. weight of ingots versus discard ratio, weight of ingots versus welds in the equipment).

04

Recommendations about codes and standards

WENRA supports the actions regarding the risk of carbon macro-segregation in large forgings initiated by the MDEP Codes and standards WG with the standards-developing organizations by:

- Reviewing the design and manufacturing provisions in existing codes;
- Improving the qualification of manufacturing techniques, in particular regarding the definition of acceptance criteria and development of controls for ensuring that those criteria are met.