Optimization and development of the manufacturing process of hexagonal wrapper tubes for ASTRID first core sub-assemblies

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OPTIMIZATION AND DEVELOPMENT OF THE MANUFACTURING PROCESS OF HEXAGONAL WRAPPER TUBES FOR ASTRID FIRST CORE SUB-ASSEMBLIES

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The CEA has designed an innovative fast sodium reactor, whose ASTRID is the prototype. The main different objectives are to reduce investment costs, operating costs and fuel cycle costs, to induce better management of accidents, and to be able to withstand the risk of proliferation.

Among core components under study, the hexagonal wrapper tube is a major element of the shell of sub-assembly. Based on accumulated experience regarding the significant feedback on Phenix and SuperPhenix French reactors, the improvement of the ASTRID first core design involves producing hexagonal tubes with novel geometrical and dimensional characteristics. Particularly, the objective is to provide longer hexagonal tubes with a larger distance across flats, compared to hexagonal tubes produced for Phenix sub-assemblies.

In the framework of the industrial development of the production, some critical points concerning manufacturing processes have been identified and induce questions concerning the industrial feasibility of hexagonal tubes with specified geometry and dimensions. Indeed, the route designed for Phenix and SuperPhenix hexagonal tubes is no longer available, due to the modifications or the dismantling of some historic manufacturing facilities.

Feasibility studies are necessary to determine whether present-day equipment capacities are suitable to produce tubes with required geometry and dimensions. Moreover, some environmental standards have been tightened up and induce consequently an adaptation or a development of innovative processes, particularly for the lubrication technology applied during cold working process. Finally, the development of new methods of non-destructive tests is required in order to ensure the quality of the final tube with hexagonal shape.

I. INTRODUCTION

The world energy demand is growing very fast due to the increase in world population and the swift development of the developing or newly industrialized countries like the People's Republic of China or the Republic of India. In order to respond to the critical and quick growing need, the new means of energy production have to be safe and efficient and be characterized by a low impact on the environment. Consequently, the increase in energy production is a real challenge in terms of technology and industrial developments.

The nuclear energy shows some advantages among all the other energy sources like, for example, the limitation of greenhouse gas emission, considering the quantity of produced energy. The development of the current nuclear technology is a real opportunity to improve efficiency and safety of the future nuclear reactors. In this context, the fast neutron reactors technology represents significant advantages to reach different objectives related to energy production: reduction of operating costs, better management of uranium resources and decrease in quantity of long-life radioactive waste.

Thanks to the feedback and the accumulated experience of Phénix and SuperPhénix French reactors, CEA has designed a new fast neutron reactor core prototype cooled by liquid sodium, called ASTRID. This innovative project leads to develop a core structure with an improved geometry, which has a significant impact on the sub-assembly characteristics.

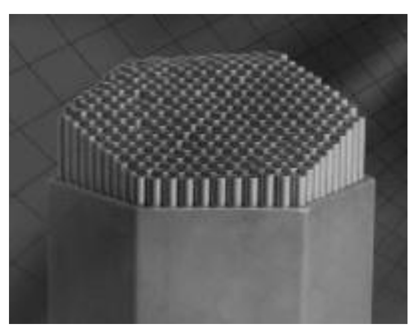

Fig. 1. Picture of a fuel sub-assembly, with a hexagonal tube wrapping the fuel pins (Ref. 1).

Sub-assemblies of the core are characterized by different functions (fuel sub-assemblies, control rod sub-assemblies…) and each of them is composed by several structural elements. The hexagonal tube is a major element dedicated to wrap up the inside components of the sub-assembly (Fig.1). It is characterized by two main functions: to ensure the mechanical strength of the sub-assembly and to guarantee its cooling by an efficient sodium flow.

The ASTRID first core design involves producing hexagonal tubes with innovative geometrical and dimensional characteristics. Particularly, the objective is to provide longer hexagonal tubes with a larger distance across flats, compared to hexagonal tubes produced for Phenix sub-assemblies. The required development of the hexagonal tubes manufacturing process and associated nondestructive tests represents a real industrial challenge.

II. MATERIAL AND MANUFACTURING PROCESS

II.A. Material

Among the different steel grades which have been tested in Phénix reactor, Grade EM10 steel is a 9Cr-1Mo tempered martensite steel which has been selected as reference material for hexagonal wrapper tubes. Its targeted chemical composition is presented in Table 1.

TABLE I. Targeted chemical composition of Grade EM10 steel (Ref. 1)

Elements	C	Si	Mn	Cr	Ni	Mo
Wt. %	0.10	0.35	0.50	8.5	0.50	1.0

Compared to austenitic steel and other 9% chromium tempered martensite steels, Grade EM10 steel is characterized by higher stability of microstructural and mechanical properties under irradiation (Ref. 2). The selection of this material, coupled to the increase in dimensional characteristics of hexagonal tubes, induce an adaptation of the manufacturing process and the associated nondestructive control tests which were used on hexagonal tubes produced for Phénix sub-assemblies.

In order to guarantee acceptable microstructural properties, inclusion rating (for thick and thin inclusion) and ferrite content are measured on the ingot before working process. Rated values have to be lower than maximum specified values.

II.B. Manufacturing process

In the past, hexagonal tubes in Grade EM10 were manufactured for the sub-assemblies of the Phénix core reactor. Even if the dimensions of these tubes are different from the dimensions of the hexagonal tubes studied for ASTRID reactor, the manufacturing process used in the past gives very important information in order to help to develop a new fabrication route, leading to manufacture hexagonal tubes with ASTRID specifications.

The manufacturing process used for the hexagonal tubes of Phénix sub-assemblies is presented in Fig. 2. It is composed by a first hot extrusion step, followed by several successive cold drawing steps and intermediate heat treatments.

The specifications impose that all heat treatments have to be performed under vacuum, except for normalizing and tempering which can carried out under neutral atmosphere. After the final heat treatment, the hexagonal tubes are cleaned before a passivation step realized in a nitric acid bath.

The inclusion rating and ferrite content are measured on the final products and have to be lower than specified values. Moreover, mechanical properties are controlled with tests performed on specimens machined on final hexagonal tubes. Material has to be characterized by minimum values of resilience, yield strength, maximum tensile strength and fracture elongation at 20°C and 400°C exposed in the specifications. Finally, nondestructive tests (ultrasonic and dimensional tests) are performed on each manufactured tubes.

III. DEVELOPMENT OF THE INDUSTRIAL PROCESS

III.A. Identified problems

Nowadays, several critical problems are identified concerning the development of the industrial production of hexagonal tubes.

The society Valinox Nucléaire is considered as the historical supplier of hexagonal tubes for the Phénix and SuperPhénix sub-assemblies. However, in 2015, the production is stopped and the production facilities used in the past are not still available easily.

The forming process of the hexagonal shape from a round tube is considered as a critical step of the process. Indeed, considering the high level of deformation induces a risk of damage on the tube. In the past, oxalating

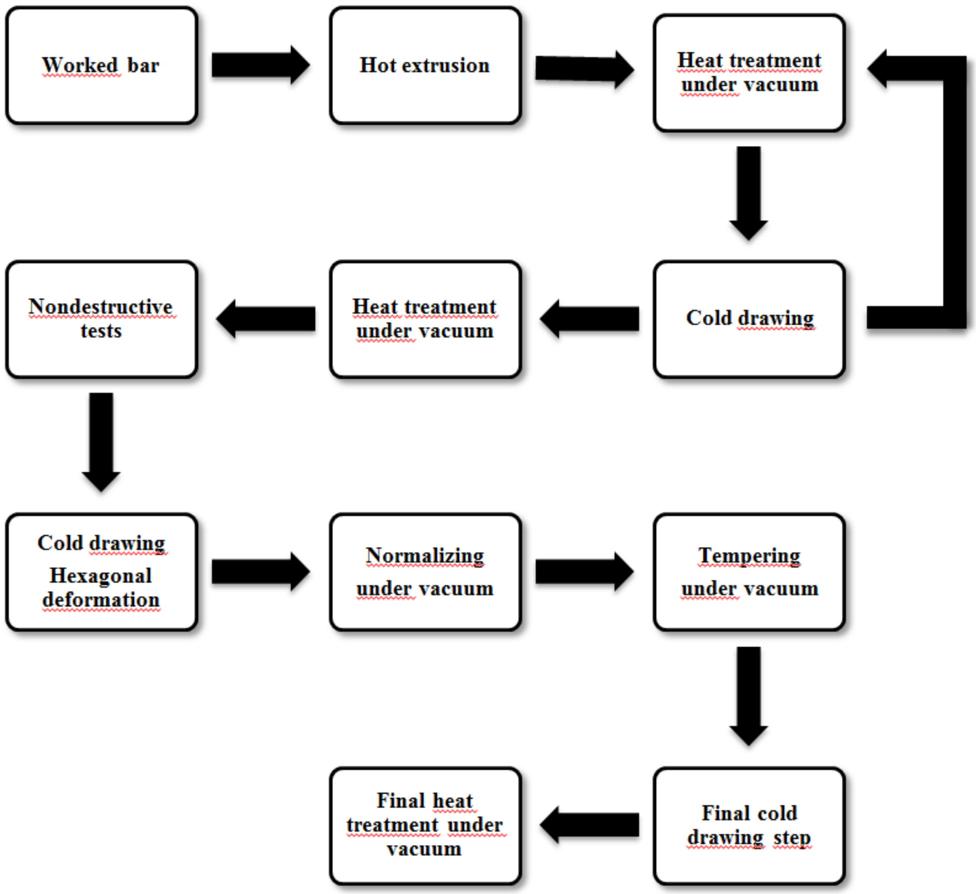

Fig. 2. Manufacturing process used for the hexagonal tubes of Phénix sub-assemblies.

solution was used in order to obtain a sufficient lubrication during the cold drawing step. However, the oxalating process needs to use polluting chemical products, which cannot be use nowadays because of stricter environmental regulations. The development of a new lubrication technique is required to guarantee the forming process of hexagonal shape without degradation of the quality of the products.

In the past, the available technology did not permit operator to perform nondestructive test (ultrasonic tests) on the final products, because of the small values of intern corner radius of the hexagon. The control of this part of the tube was only visual. Nowadays, this process is not acceptable and must be improved. On the one hand, nondestructive tests (ultrasonic or edit current tests) have to be adapted and automated on the hexagonal shape, inducing a complete control of the final products. On the other hand, specifications of the acceptable damage have to be defined, because data and corresponding tests are not available for the former hexagonal tubes used for Phénix sub-assemblies.

The specifications of hexagonal tubes impose that the atmosphere used during most of heat treatments is vacuum. This requirement induces some difficulties in terms of availability of equipment in the industrial fabric, considering the hexagonal tube dimensions. Indeed, the achievement of heat treatments under vacuum of hexagonal tubes involves using large furnaces, excluding continuous furnaces, more common in industry.

III.B. Project approach

Considering the different identified critical points of the manufacturing process of hexagonal tubes, the first approach defined in the project is the identification of potential suppliers. This strategy is divided into seven main points:

1. Define a technical specification of the hexagonal tubes for ASTRID sub-assemblies,
2. Write a form “Request For Information” focused on the capabilities a supplier,

3. Identified some potential suppliers,
4. Request the identified suppliers,
5. Study data collected,
6. Select three suppliers,
7. Summarize the main conclusions of the approach.

A draft document of specifications for hexagonal tubes of ASTRID sub-assemblies has been written. It takes requirement on the geometry, dimensions and steps of manufacturing process into account. However, some data, concerning for example the heat treatments conditions or dimensional tolerances have to be discussed with the supplier. Indeed, these values have to be adapted to the possibilities and capacities of the facilities of the manufacturer, within the limits of the imposed geometry of ASTRID sub-assemblies and the respect of imposed microstructural and mechanical properties of the hexagonal tubes.

A form "Request For Information" have been created and edited. The document integrates three main parts: general information, financial information and technical information. The objective of this document is to collect some data about the production means of a manufacturer, its experience and capacities related to the production of hexagonal tubes. As a first step, the "Request For Information" document was sent to 14 companies in Europe, identified as potential suppliers of hexagonal tubes. In a second step, this document will be send to other companies located outside Europe. CEA is now collecting a first set of data from European companies and studying it. After this step, three companies will be selected to work on a feasibility study, leading to manufacture a prototype of hexagonal tube.

IV. CONCLUSION

In the framework of the industrial development of the production, some critical points concerning manufacturing processes have been identified and induce questions concerning the industrial feasibility of hexagonal tubes with specified geometry and dimensions. Indeed, the route designed for Phenix and SuperPhenix hexagonal tubes is no longer available, due to the modifications or the dismantling of some historic manufacturing facilities.

Feasibility studies are necessary to determine whether present-day equipment capacities are suitable to produce tubes with required geometry and dimensions. Moreover, some environmental standards have been tightened up and induce consequently an adaptation or a development of innovative processes, particularly for the lubrication technology applied during cold working process. Finally, the development of new methods of non-destructive tests is required in order to ensure the quality of the final tube with hexagonal shape.

Before launching the feasibly study, CEA is now working on a project with an objective of identification, evaluation and selection of potential suppliers of hexagonal tubes to manufacture the ASTRID sub-assemblies.

REFERENCES

1. E. DELOYE and P. TARDIF, "Les tubes hexagonaux de la Génération IV", *20ème Congrès Français de Mécanique, Besançon*, August 29 - Septembre 2, 2011.
2. J.L. SERAN, A. ALAMO, A. MAILLARD, H. TOURON, J.C. BRACHET, P. DUBUISSON and O. RABOUILLE, "Pre- and post-irradiation mechanical properties of ferritic-martensitic steels for fusion applications: EM10 base metal and EM10/EM10 welds," *Journal of Nuclear Materials*, **212-215**, 588-593 (1994).