2011 International Nuclear Atlantic Conference - INAC 2011
Belo Horizonte,MG, Brazil, October 24-28, 2011
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
***ISBN:* 978-85-99141-04-5**

PARAMETRIC STUDY OF THE DEFORMATION OF DISPERSION FUEL PLATES

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ABSTRACT

The Nuclear and Energy Research Institute - IPEN-CNEN/SP produces routinely the nuclear fuel necessary for operating its research reactor, IEA-R1. This fuel consists of fuel plates containing U_3Si_2-Al composites as the meat, which are fabricated by rolling. The rolling process currently deployed was developed with base on information obtained from literature, which were used as premises for defining the current manufacturing procedures, according to a methodology with essentially empirical character. Despite the current rolling process to be perfectly stable and highly reproducible, it is not well characterized and therefore is not fully known. The objective of this work is to characterize the rolling process for producing fuel plates, presenting results of the evolution of all parameters of technological interest, after each rolling pass, obtaining information along the fuel plate deformation during the rolling process.

1. INTRODUCTION

Research reactors are used primarily for production of radioisotopes and materials testing. The IEA-R1 research reactor of IPEN/CNEN-SP, is used for primary radioisotopes production, mainly ^{131}I. The reactor is responsible for meeting 80% of the national demand for radioisotopes, and also sealed radioactive sources for industrial application. The fuel element for the IEA-R1 reactor is formed by assembling a series of spaced fuel plates, allowing the passage of a water flow that serves as coolant and moderator. The fuel element is composed of 18 flat and parallel fuel plates. The fuel plates consist of a meat containing the fissile material, which is entirely cladded with aluminum. The fuel plates are manufactured by adopting the traditional technique of assembling meat, frame and claddings with subsequent rolling. This technique is known internationally under the name "picture frame technique" [1,2]. Powder metallurgy techniques are used in manufacturing the meats for the fuel plates (briquettes), which are composed of cermets (ceramic-metal composites) containing U_3O_8 or U_3Si_2 powder enriched to 20% in the ^{235}U isotope (nuclear fuel material) together with aluminum powder (structural material of the meat). The main manufacturing steps of this kind of fuel are the production of briquettes by pressing and manufacturing of fuel plates by rolling.

Since 1988, IPEN has been manufacturing fuel for the IEA-R1 reactor. The fuel currently produced adopts the U_3Si_2-Al dispersion with uranium concentration of 3.0 gU/cm^3 [3,4]. The rolling procedures currently implemented have been developed based on literature information [5,6,7], which were used as premises for defining the current manufacturing procedures, according to an essentially empirical methodology. For this reason, despite the current rolling process is perfectly stable and highly reproductive, it is not well characterized and therefore is not fully understood.

A complete characterization of the rolling process adopted for fabricating fuel plates is important in order to understand and correct possible deviations that might occur in the manufacturing process. Also, a more deep understanding of this process allow to adjust it quickly to new specifications, in the case of manufacturing fuels for use in other research reactors, as the Brazilian Multipurpose Reactor - RMB. The objective of this work is to characterize the rolling process currently adopted by IPEN, specifically regarding to the evolution of dimensional parameters of the fuel plate as a function of its deformation in the rolling process.

2. EXPERIMENTAL

The fuel plate fabrication process is performed with nine hot-rolling passes and three cold-rolling passes. Thus, 13 briquettes with U_3Si_2-Al dispersions were produced according to the current specifications, with a uranium density of 3.0 gU/cm^3. This is the kind of fuel made on the production line of IPEN for use in IEA-R1 reactor. All briquettes were assembled according the picture-frame technique [1,2] to form the sets for rolling, as specified for the fuel plates production. A plate was removed after each rolling pass, generating a sample at each stage of the deformation of the set. A briquette was studied just after pressing, ie, without undergoing the rolling process. This briquette provided microstructural information of the initial fuel meat, ie, size distribution and porosity of the starting fissile material.

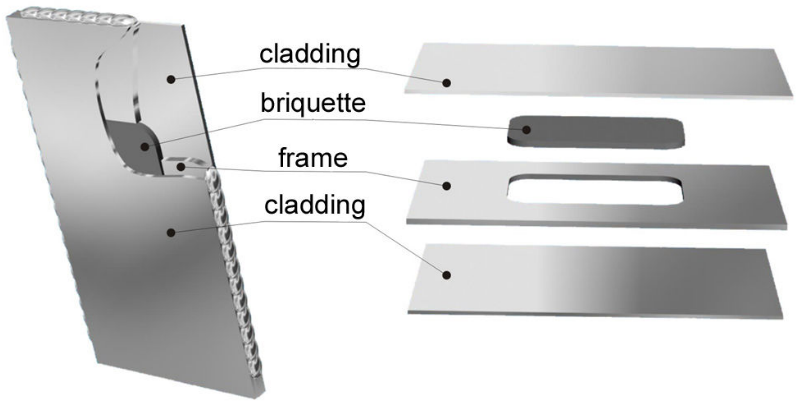
All produced briquettes meet the specification and were manufactured strictly according to procedures well established. In this way, samples taken after each rolling pass represents the status of a fuel plate in that stage of the rolling process. The samples obtained were analyzed for the most important aspects of the U_3Si_2-Al meat, namely:

1 - length of the fuel meat;
2 - width of the fuel meat;
3 – cladding thickness in the meat region;
4 - thickness of the fuel meat;
5 - thickening of the meat at its end, which is a defect known as "dogboning";

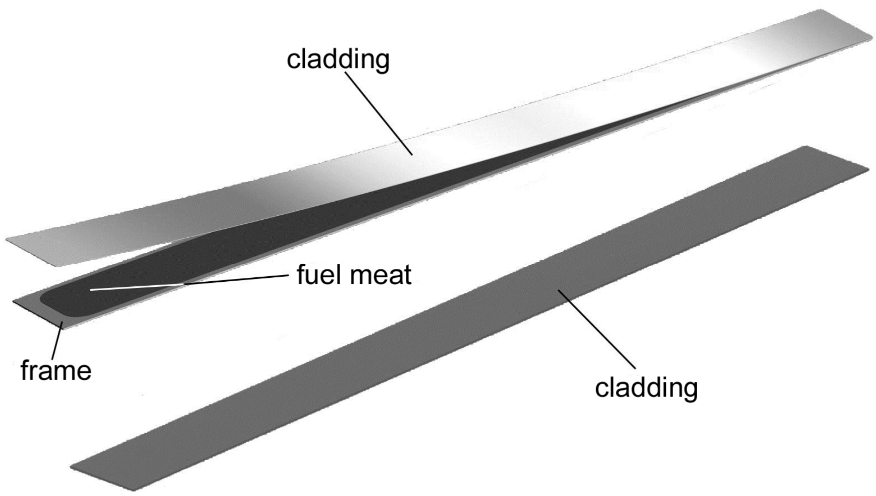
These parameters were determined with the aid of X-rays and traditional measurement instruments, such as rulers and calipers, as well as traditional metallography techniques and image analysis. Fig. 1 illustrates the samples fabrication technique before (Fig. 1A) and after rolling (Fig. 1B).

3. RESULTS AND DISCUSSION

A dispersion fuel meat is characterized by containing particles of a uranium fissile compound dispersed as uniformly as possible in an inert metal matrix, or non-fissile matrix, which serves to remove and transfer the heat generated in fission to the coolant, and to promote the mechanical stiffness of the fuel plate. In an ideal dispersion, the fissile particles must be isolated from each other, surrounded by the metal structure. Due to the characteristics of the manufacturing process of this type of fuel, it is impractical to obtain a perfect dispersion. In the case of fuel produced at IPEN, the fissile material used is the uranium silicide, U_3Si_2, and the structural non-fissile material is aluminum. Fig. 2 shows optical micrographs illustrating the typical appearance of an U_3Si_2-Al dispersion manufactured at IPEN.



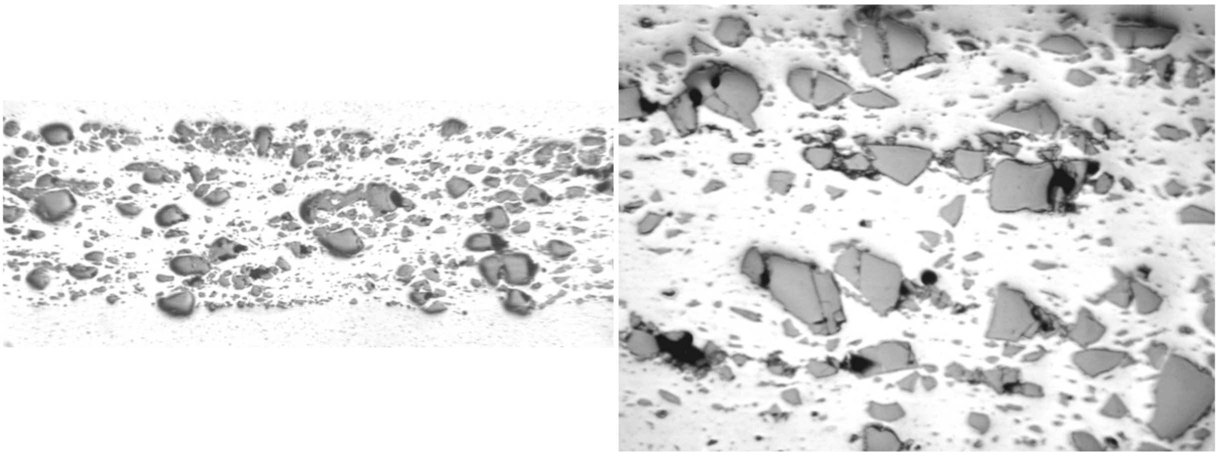
(A)



(B)

Figure 1. Pictures illustrating the sample fabrication technique.
A –before rolling
B –after rolling

During rolling, the fuel plate undergoes elongation to a greater degree, and small enlargement, but not negligible. As the width and length of the meat in the finished fuel plate must meet the current specifications, the knowledge of these values as a function of the thickness reduction during rolling is an important tool. This data can support the development of fabrication procedures for new fuel or changes in the existing ones. The graphs in Fig. 3 show the elongation and enlargement results.



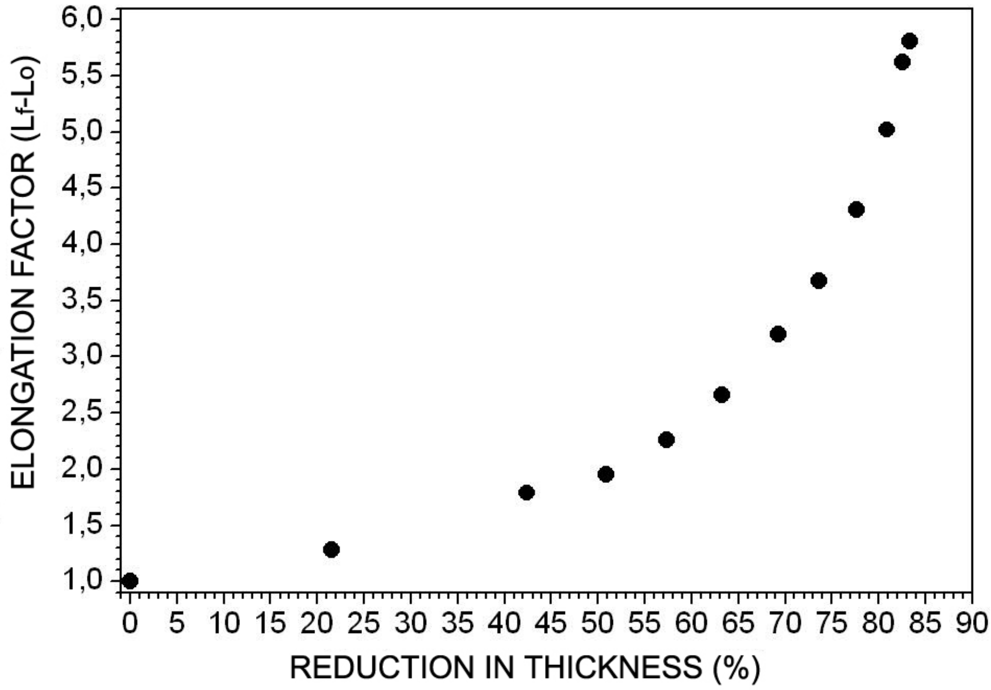
(A) (B)

Figure 2. Optical micrographs illustrating the microstructure of the U_3Si_2-Al dispersion fuel manufactured at IPEN.
A – 50 X
B –100 X

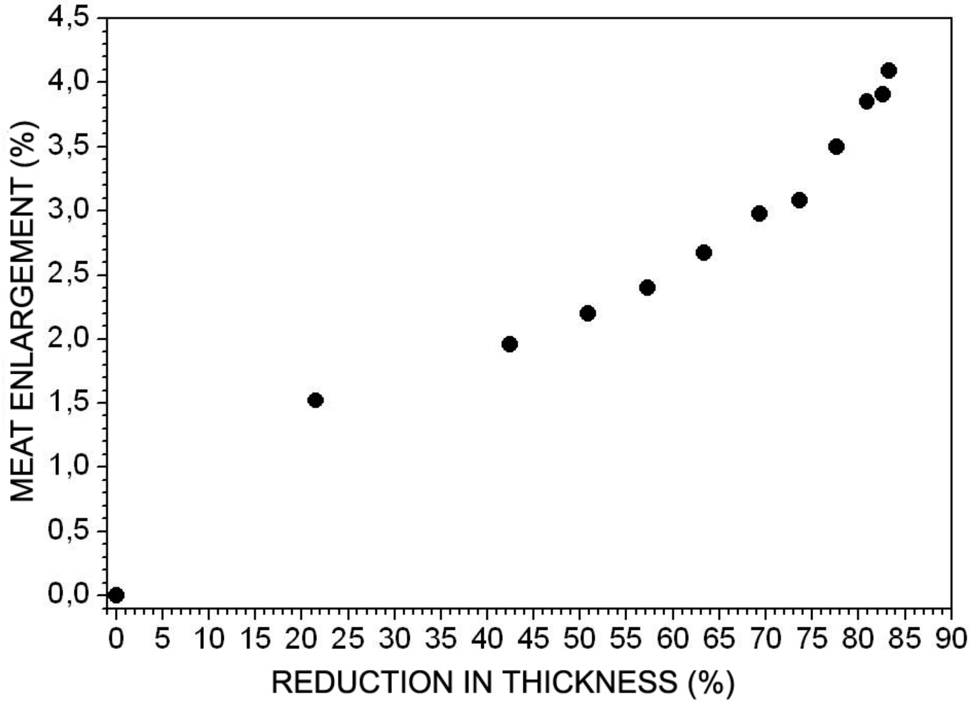
One of the most important parameters in the fuel plate is the cladding thickness, since this layer of aluminum ensures the isolation of the fuel meat from the reactor environment. If this cladding fails, the core is exposed and the reactor environment is contaminated with high activity radioactive material. For this reason, the thickness of the cladding on the finished fuel plate is one of the most important specifications for this type of fuel. Depending on the design specifications for the cladding and meat thicknesses of the finished fuel plate, the thicknesses of the starting briquette and aluminum cladding sheets must be precisely defined, which defines the overall thickness of the initial set for rolling The precise design of these dimensions depends on the knowledge of the behavior of the thicknesses of each of the components of the meat-frame-claddings as a function of deformation in rolling. Fig. 4A shows the relation between the meat and cladding thicknesses of the fuel plate due to the thickness reduction of the meat-frame-claddings assembly during rolling. The manufacturing takes nine hot-rolling passes and two cold-rolling passes.

It is observed that the evolution of deformation is not the same for the meat and claddings. The initial E_{clad}/ E_{meat}= 0.6 ratio decreases with the evolution of deformation, showing that the claddings deform preferentially to the meat in the hot-rolling, and reversing this behavior in cold-rolling. Due to the increased resistance to deformation of the meat, which is caused by the presence of U_3Si_2 particles, the elongation in the claddings is higher. The initial ratio between the thicknesses of the meat and claddings was decreased from the original value 0.6

to 0.5 in the finished fuel plate. Fig. 4B illustrates a typical end defect known as "fish tail" caused by the difference in strength between the meat and the claddings.

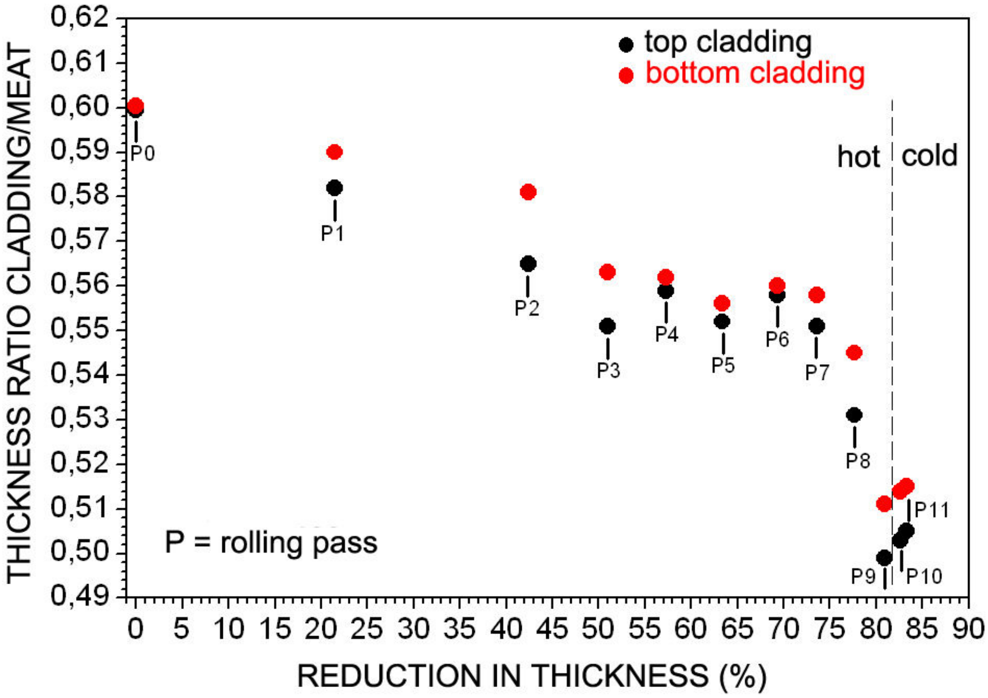


(A)

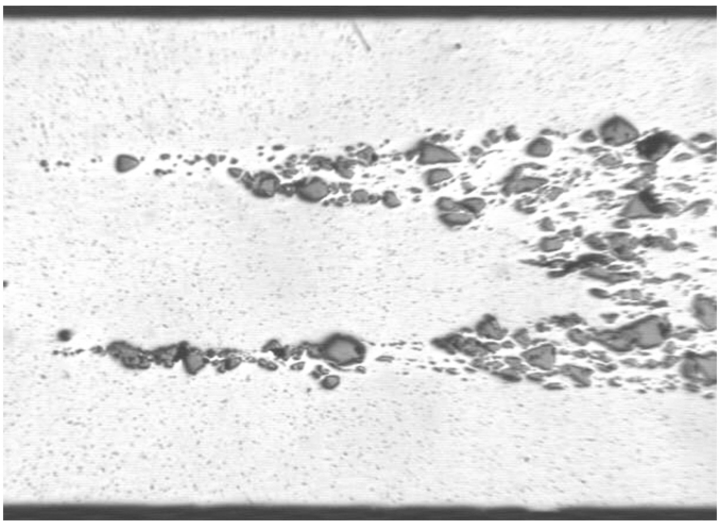


(B)

Figure 3. Elongation factor (A) and percentage enlargement (B) of the fuel plate meat as a function of deformation in rolling.



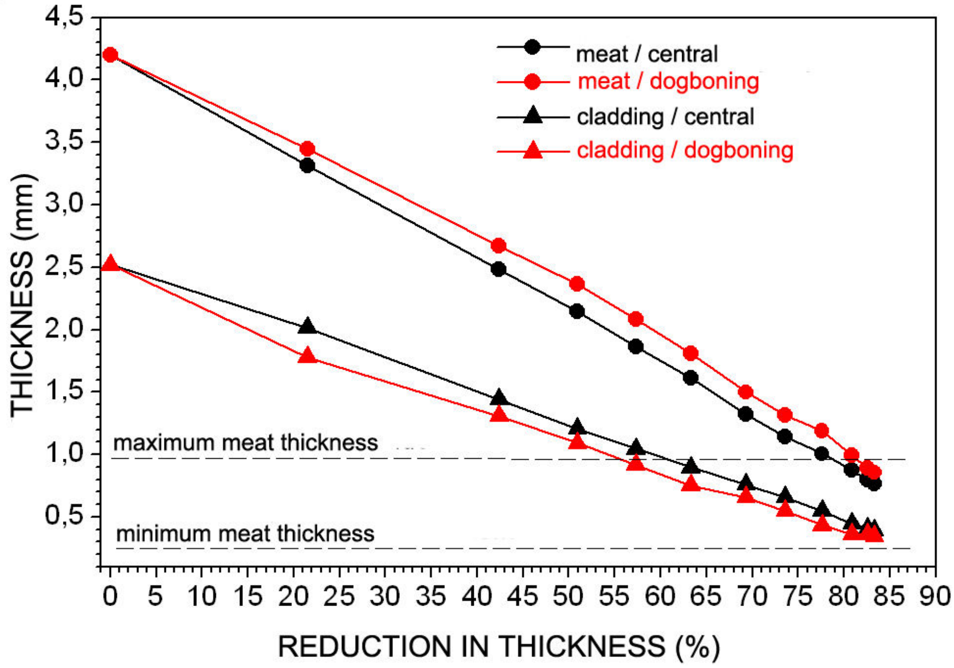
(A)



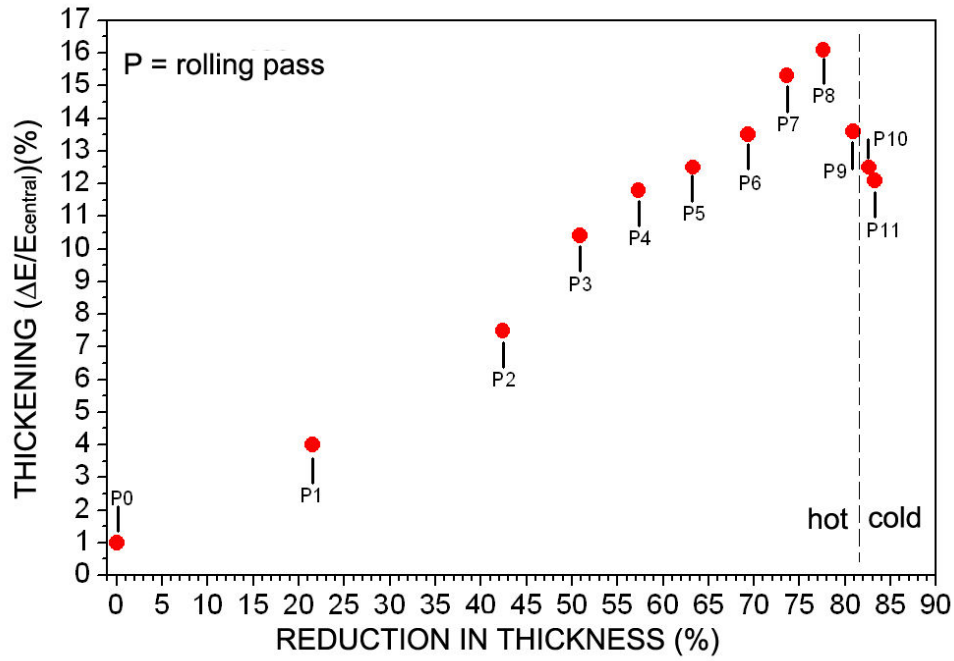
(B)

Figure 4. Evolution of the meat and cladding thicknesses as a function of deformation in rolling (A) and typical "fish-tail" end-defect (B).

Another typical end defect is known as "dogboning", which is the meat thickening at its ends in the longitudinal direction during rolling (rolling direction). This phenomenon is usual when components with different mechanical properties are rolled simultaneously. In the case of fuel plates, the meat is more resistant to deformation than the other aluminum components of the set (frame and claddings). Because of this, the rolling process produces the meat edges thicker than its central part. A longitudinal cross section of the meat with their thicker ends resembles a dog bone, which originated the name of the defect.



(A)



(B)

Figure 5. Evolution of the meat and cladding thicknesses on the dog-boning (A) and evolution of the thickening factor, depending on the deformation in rolling (B).

This type of defect is worrisome for two reasons. The first concerns to the decrease in cladding thickness at the edges of the fuel plate on the ends of the meat, where the defect occurred. The second one relates to the greater amount of fissile material in the regions of defect, since in these regions the meat thickness is greater and, consequently, the amount of uranium per unit area is also higher. The second reason leads to an excess of reactivity in the regions of defect, leading to a higher heat flow and therefore a higher temperature.

Therefore, the thickening, defined as the difference between the average thickness in the central zone of the fuel plate meat and its maximum thickness in the end defects zone (in percentage) should be known and used in the fuel design to compensate the thickness decreasing of claddings due to this inevitable defect. Fig. 5 shows the evolution of the thickening factor as a function of deformation in rolling.

4. CONCLUSIONS

This work studied the evolution of the dimensional parameters of the fuel plate meat as a function of its deformation in the rolling process. Apart from better knowledge of the manufacturing process of fuel plates, these results help to design new geometries of fuel plates. So, this study prepares IPEN to the fuel for the new producing radioisotopes research reactor planned to be built in Brazil, the Brazilian Multipurpose Reactor - RMB. As a continuation of this work, other important aspects of the fuel plate will be studied as a function of deformation in rolling, such as porosity and U_3Si_2 particle size of the meat and the bonding between meat and cladding.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to the Fundação de Amparo à Pesquisa do Estado de São Paulo – FAPESP, for their support in improving the infrastructure of the Nuclear Fuel Center of IPEN, through the FAPESP Project 2007/07769-7, without which this work could not have been accomplished.

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