# RE–QUALIFICATION OF MTR-TYPE FUEL PLATES FABRICATION PROCESS

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## ABSTRACT

The fabricability issues with increased uranium loading due to use low enrichment of uranium (LEU), i.e. less than 20 % of $U^{235}$, increase the problems which occur during compact manufacturing, roll bonding of the fuel plates, potential difficulty in forming during rolling process, mechanical integrity of the core during fabrication, potential difficulty in meat homogeneity, and the ability to fabricate plates with thicker core as a means of increasing total uranium loading. To produce MTR- type fuel plates with high uranium loading (HUL) and keep the required quality of these plates, many of qualification process must be done in the commissioning step of fuel fabrication plant. After that any changing of the fabrication parameters, for example changing of any of the raw materials, devises, operators, and etc., a re-qualification process should be done in order to keep the quality of produced plates. Objective of the present work is the general description of the activities to be accomplished for re-qualification of manufacturing MTR- type nuclear fuel plates. For each process to be re-qualified, a detailed of re-qualification process were established.

## 1 Introduction

The use of LEU in the fabrication of the MTR- type fuel elements for operation of research rectors necessitate the increase of uranium loading in the fuel core plates. This mean increase in the core thickness. This could lead to problems concerning the plates clad, especially at the plate ends when dog-boning and fish tail can take place and problems in the plates core homogeneity, potential difficulty in forming during rolling process, and mechanical integrity of the core during fabrication [1-6].The expected in-reactor performance as the oxide content is increased and the aluminum is decreased depends primarily on the mechanical integrity of the core, the thermal conductivity, and the increased potential for $Al\text{-}U_3O_8$ thermite reactions in core meltdown accidents. The qualification of low enriched uranium ( LEU ) fuels requires many tests to achieve the required specification of Fuel plates. Fulfill these specification demonstrate the ability of the fuel to withstand research reactor operating limits (i.e. high power densities) up to economically viable burn-up values. The $U_3O_8$ MTR-type fuel has been found to perform well under irradiation tests, even with uranium densities up to 4.20 $gU/cm^3$[ 3, 4, 5-9].

Each type of MTR fuel element is produced in accordance with a manufacturing specification and a set of manufacturing drawings agreed between the fabricator and the reactor operator or his representative. The specification sets down the scope and general conditions, the requirements of the manufacturing method, together with the inspection requirements and acceptance criteria. In addition to the specification, an inspection schedule is normally produced which includes all of the supporting documentation such as the inspection and record sheet and certification[3,4,6,10].

The MTR-type fuel plates production in which the starting materials are uranium oxide ($U_3O_8$) powder, pure aluminum powder , and nuclear grade 6061 aluminum alloy in sheets the different dimensions as a raw materials, are processed through a series of the manufacturing, inspection, and quality control plan to produce the final specified MTR-type fuel elements[7]

The re-qualification process must be done From time to time due to stop of production for long period of time, any changing the raw materials used in MTR fuel plates fabrication, using a new device, and using a new operator in the production steps. For example, the new raw material of course was fulfilled the geranial specification. However, there is difference of the properties between the old and new raw material. Even this little difference is satisfy the specified values but at the same time could be affected the quality of the produced fuel plates. The re-qualification step is done to ensure that the produced fuel plates are fulfilled the required quality which are agreed between the fabricator and the reactor operator or his representative as well as to minimize the rejection of fuel plates during fabrication process and this is the main aim of this work.

## 2 Start up of re-qualification processes.

Prior to starting a re-qualification, the equipment, devices and tooling are verified to be in proper operational condition. Also, the standard or normal or average values of the operating parameters are used. During the re-qualification process , the applicable Working Instructions, Quality Control Instructions, quality control characteristics of the products and qualification data during the commissioning step as well as the re-qualification data must be available. These data are very important to decrease the cost and the period of the re-qualification processes. After re-qualification processes, the high quality of the fuel plates could be obtained.

## 3 Fabrication steps of the fuel plates

The fabrication of this type of fuel plates is carried out by using picture-frame technique, Fig.1. This method is used to produce the preplate (sandwich). The sandwich plate consists of a core plate (the picture) made from a mixture of uranium compound ($U_3O_8$) and aluminum powder, which is surrounded by a frame and two cover plates, made from 6061 aluminum alloy (the cladding). The three-layer assembly is welded and rolled in several passes at about 500 $^oC$. During hot rolling passes, roll bonding takes place between all the sandwich components. Then, the final plate thickness is obtained by a cold rolling pass. Obtaining the fuel plate by core location, plate shearing, machining, cleaning. Then the inspection and quality control for the produced fuel plates are taken place for settlement the re-qualification process[2]. The number of fuel plates produced for re-qualification step depends on the situation and changing of parameters. For re-qualification steps 15 to 25 plates could be produced.

## 4 The inspection procedures

### 4.1 Nondestructive testing

#### 4.1.1 Radiographic examination

Radiography was used to examine the plates for core and edge border dimensions (core location), high-density of fuel particles, fuel particles in the edge and borders, and fuel core homogeneity. It was found that radiographs are suitable for above. Two radiographs of different intensities are done: One suitable for examining core location and fuel particles in the edge and borders and the other suitable for core homogeneity.

#### 4.1.2 The blister test

The most effective quality check on bonding is the blister test. The chosen blister temperature depends on the selected cladding material and should be only slightly different from the hot rolling temperature. The temperature range is normally between 410°C and 500°C[7].

In the blister test, the fuel plates were held at 500 $^oC$ for one hour. followed by a cooling in furnace from 500$^o$C to 200$^o$C at the cooling rate of 30 $^oC$ per hour. The plates are taken out of the furnace after being cooled to room temperature. The blistering area for each specimen is the sum of the all areas of the single blisters. Typical examples of the blistering area formed during blister test in the roll bonded plates is shown in Fig. 3. By this way the blistering area could be observed and measured. The areas of the blisters and their position control the quality of fuel plates. Blister in a fuel plate could lead to the rejection of this plate.

Any fuel plate exhibiting blisters on the active surface, delimited by the fuel core, or at a distance less than 3 mm from the closest fuel core boarders, shall be rejected. On the other hand, the fuel plate exhibiting of blister more than 2 mm diameter outside the active surface and at a distance more than 3 mm from the closest core boarders shall be rejected. The blister test plays an important part in the fuel plate fabrication, not only in the blister phenomena, but also it enhances the metallurgical bond between fuel core and cover, and also between the frame and cover[7,11].

### 4.1.3 Bending Test

The bend tests are generally used in the weld qualification process for roll bonding . Bend testing is performed by clamping a section of the non-fueled region of the welded plate into a fixture and bending it over a radius. The plate is bent four times for a total of 360$^{o}$. If any delimitation is noted the bond is considered unacceptable. As this test is destructive in nature, it is only performed on adjacent material removed in the sizing of the fuel plate[12]. As such, the test is performed only to test the cladding to cladding bond (the bimetal bond between the fuel core and the cladding is not robust enough to survive this test).

## 4.2 The destructive testing

the clad thickness at the ends is very important, where there is a certain thickness value which cannot be allowable to reduce this value. This case is known as dogboning phenomena. Therefore, the product should be examined to chick if there is dogboning or not. In this case the thickness should be checked to assure that is still in the required specification. This step was carried out by destructive tests. Normally this is carried out for one plate for every 100 plats. A fuel plate for this test is selected according to an inspection scheme and four specimens are cut out from the plate for metallographic examinations, Figure 1 Demonstrates such a sampling scheme. After preparation these specimens[9]. The cladding thickness can be affected by the parameters, such as mechanical properties of aluminum alloys used as cladding for fuel core, characteristics of the $U_3O_8$ powder used as fuel core, aluminum powder used as dispersed matrix, roll mill diameter and speed, and ect.,. Also, this test can be used for examine the metallurgical bond between aluminum cladding as well as between fuel core and aluminum cladding.

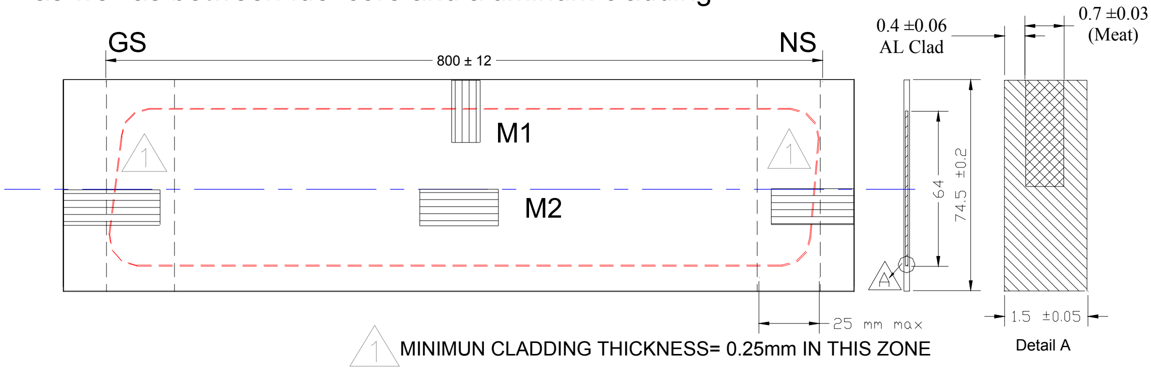



Figure 1 Sampling scheme for metallographic examinations

# 5 Studies cases for re-qualification processes

## 5.1 Using new roll mills

During fabrication of fuel plates the roll mills had surface problem. This problem results in bad quality of the produced fuel plates. So, the changing of the roll mills was required. The new roll mills were the same diameter and material of the old ones. The old roll mills were uninstalled and the new ones were installed. This process lead to making the re-qualification processes for the fuel plates rolling process. The re-qualification processes for the fuel plates rolling process started with operation test of rolling machine to adjust the parallelism between the two roll mills and digital reading of the distance between them by using AA6061 as the same dimensions of the sandwich plate. Then, a simulation of the fuel plates rolling was made by using natural uranium oxide ($U_3O_8$), which is alike real material, instated of 20 % uranium oxide ($U_3O_8$) and all above mentioned inspection tests must be done to readjustable of the rolling process. Also, to adjust the curvature of the fuel core which is the one of normal problems take place in the fabrication process of the fuel plates [10] as well as fuel core length, meat homogeneity, clad thickness of two sides of fuel plates and meat thickness at middle and two ends of fuel plate. After that the real materials were fabricated but first with few number of fuel plate. Again, all above mentioned inspection tests was done to insure that the required quality of the fuel plates was obtained. About twenty seven fuel plates were produced for this process. Then the normal fuel plates rolling process take place again.

## 5.2 Changing of AA6061 cladding material

From time to time, the raw materials used in manufacturing of the MTR-type fuel plates are changed with new ones. The changing of any of the raw materials could be affecting the quality of the fuel plates. So, in such cases the re-qualification processes are required. In the studied case, the required re-qualification processes of changing of AA6061 were described as follows;

### 5.2.1 Chemical composition and mechanical properties of AA6061 cladding materials

The comparison between the old and new AA6061 cladding materials concerning to chemical composition and mechanical properties are illustrated in Table 1 and 2. As shown in these Tables both AA6061 cladding materials were satisfy the specified values but there are small difference in both chemical composition and mechanical properties

Table 1 Chemical composition of AA6061

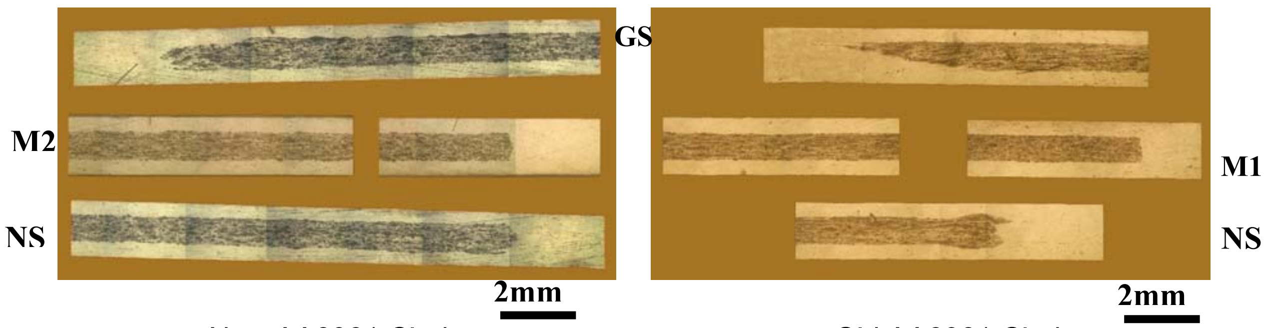
| Element | | Mg % | Si % | Cu % | Cr % | Fe % | Mn % | Zn % | Ti % | Others % | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Specified Values** | | **0.8 - 1.2** | **0.4 - 0.8** | **0.15 – 0.4** | **0.04 - 0.35** | **≤ 0.70** | **≤ 0.15** | **≤ 0.25** | **≤ 0.15** | **≤ 0.15** | **balance** |
| **New AA6061 Clad** | **Cover** | 1.10 | 0.7 | 0.25 | 0.22 | 0.56 | 0.15 | 0.24 | 0.15 | 0.15 | balance |
| | **Frame** | 1.08 | 0.72 | 0.28 | 0.24 | 0.55 | 0.15 | 0.23 | 0.15 | 0.15 | balance |
| **Old AA6061 Clad** | **Cover** | 0.99 | 0.6 | 0.30 | 0.2 | 0.7 | 0.15 | 0.25 | 0.15 | 0.15 | balance |
| | **Frame** | 1.05 | 0.65 | 0.27 | 0.25 | 0.7 | 0.15 | 0.25 | 0.15 | 0.15 | balance |

Table 2 Mechanical properties of AA6061

| | New AA6061 Clad | | Old AA6061 Clad | | Specified Values |
|---|---|---|---|---|---|
| | Cover | Frame | Cover | Frame | |
| **Yield strength (MPa)** | 73.3 | 70.4 | 65 | 62.4 | **< 110** |
| **Ultimate strength (MPa)** | 134.08 | 133.44 | 110 | 109.8 | **< 150** |
| **Tensile elongation %** | 39.44 | 42.3 | 31.6 | 33 | **> 20** |

The re-qualification processes for the fuel plates rolling process started first with three fuel plates from the new AA6061cladding materials and two fuel plates from the old AA6061cladding materials. A comparison of the quality of fuel plates produced from both AA6061cladding materials was done. All above inspection mentioned tests were done of the new AA6061 cladding materials to determine the real quality of produced fuel plates. Also, to determine the length of fuel core of the plates by using radiographic examination as well as the minimum cladding materials thickness and maximum fuel core thickness in the bogbone zone and average and minimum thickness of both fuel core and the cladding materials in other parts of the fuel plate by using the destructive test as mentioned above. Figure 2 shows the shape of fuel core in the ending zone of the fuel plates, specimen GS and Ns as well as the shape of the fuel core in the middle of the fuel plates for both AA6061 cladding materials according to Figure 1.

It was noticeable that the two endings of fuel plates are affected by the changing of AA6061cladding materials. As shown in figure 2 the new AA6061 cladding material gives good cladding thickness at the two endings comparison with the old AA6061 cladding material. However, previous studies[2, 3, 6,10] showed the influence of the dimensions and geometrical shape of the fuel core, alloying elements added either to the core alone or the core and cladding, the method of the fuel plates assembly, and temperature of rolling on of fuel core in the ending zone of the fuel plates.




New AA6061 Clad Old AA6061 Clad

Figure 2 The shape of the fuel core ($U_3O_8$ + Al) and AA6061 Clad

## 6 Summary

The re-qualification processes are done to ensure that the produced fuel plates are fulfilled the required quality. The re-qualification processes of MTR-type fuel plates requires many fabrication processes and inspection tests, and costs a lot of money and efforts. But in the same time, these processes are given a high quality or keep the required quality, and minimized the number of rejection of produced fuel plates.

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