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# Abstract

At the present work the  $UO_2$  fuel production process was extensively studied and analyzed. The objectives of such investigation were to understand and analyze the influence of different additives and the variation of the production process steps on the microstructure and consequently in the mechanical strength of the nuclear fuel pellet.

Moreover, an improvement of the qualitative characteristics of the ceramic fuel pellets was also aimed. For this purpose  $UO_2$  pellets without additives, the so-called standard pellets, pellets containing as additive for example *AZB* (Azodicarbonamid), black  $U_3O_8$  (Oxidized uranium pellet scrap - *OS*), green  $U_3O_8$  (Oxidized uranium powder - *OP*), keratin fibers (a non conventional additive) were produced.

The introduction of these additives to the  $UO_2$  powder mixture prior or after the granulation production step and in different concentrations produced several microstructure configurations. As it would not be possible to analyze all of them here so during the investigation pre-tests some of them were separated to be studied in more detail.

Pellets with *AZB* added after the granulation presented larger grains and larger pores than those with *AZB* added before granulation, also porosity free grains and a granulate structure instead of a homogeneous one. Pellets with *OS* present fine porosity distributed all over the pellet matrix with some porosity clusters whereas pellets containing *OP* show in its matrix porosity agglomerated in form of hooks. As for the grain size, a more uniform grain size distribution can be observed in pellets *OS* than in pellets with *OP*.

The variations in the amount of keratin fibers added, sintering dwell time and green density resulted indeed in different microstructures. Nevertheless, some common characteristics among them were observed such as the presence of elongated pores, porosity clusters and larger grains located at the pellets borders while the smaller ones were concentrated more in the central part of the pellet. This distribution of grains was identified as bi-modal structure.

The mentioned microstructure aspects certainly influence on the mechanical properties of the fuel pellet. However, the sintering parameters, the green and final pellet density and the pellet dimensions also have an influence on the mechanical characteristics of the pellets. For studying the influence of all these parameters on the pellet mechanical properties four testing procedures

were utilized the so-called squirrel-cage where the mechanical resistance of the not sintered pellets against mechanical shocks was tested, the diametrical compression test (Brazilian Test) where the strength of sintered and not sintered pellets was studied, the Vickers indentation technique and the creep test where the pellet plasticity respectively at room and at elevated temperatures was analyzed.

The squirrel-cage results showed that the pellets with keratin fibers were much more mechanically resistant than those pellets without it, which means that the keratin fibers acted, prior sintering, as a powder binder increasing the cohesion among the powder granules proportionating the green pellets higher mechanical resistance against impacts.

The Brazilian test evaluated the influence of the pellet length to the pellet diameter ( $L/D$  ratio), the influence of different additives mixed to the  $UO_2$  powder and the different pellet production processes. The  $L/D$  influence analysis showed that if one fixes the pellet diameter and increase the pellet length the Weibull modulus (here a measure of the pellet lot reliability) will also increase. By comparing pellets with  $OS$ ,  $OP$  and 0.3% keratin fibers it was observed that pellets with  $OS$  presented the highest volume of pores smaller than  $10\ \mu m$  while pellets with  $OP$  and keratin presented the highest volume of pores larger than  $20\ \mu m$ . It seems that this relevant characteristic favored to the highest Weibull strength value for pellets with  $OS$ .

In the indentation test standard pellets, pellets with  $OS$  and pellets with keratin fibers were tested. The results showed that the calculated hardness for the standard pellets is slightly lower when compared to the values obtained by the pellets with keratin fibers. Also the pellets containing  $OS$  when compared to the keratin fibers pellets have in most of the cases a lower hardness. The calculated fracture toughness and fracture surface energy values show also a better mechanical behavior for the keratin fibre pellets than in the standard pellets.

Standard pellets, pellets with 30%  $OP$ , which had the smallest grain size, pellets with keratin fibers, having the bi-modal structure and pellets with chromium oxide, which had the largest grain size, were tested in the creep furnace. The results showed that all pellets with additives presented a better creep behavior than the standard pellets. Among the pellets prepared with additives the comparison clearly showed that under lower stresses pellets with smaller grains have a better creep rate. By increasing the applied stresses we observe an improvement of the creep rate of the pellets with chromium oxide and keratin fibre even slightly overcoming the pellets with 30%  $OP$  at the highest applied stress.