MATERIALS PROPERTY CHANGES AFTER IRRADIATION EVLAUATED USING SMALL SCALE MECHANICAL TESTING.

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Short abstract: Radiation damage can lead to significant property changes in structural materials. Radiation induced swelling, embrittlement or increase in yield strength are just a few. The dose, dose rate and temperature together determine the effect on the material which can have significant engineering impact. Therefore, it is key to understand how a material changes under radiation and being able to predict the property changes. Small scale mechanical testing offers a wide range of benefits especially when working with materials in nuclear application. The reduced size allows to handle highly radioactive materials while also enabling ion beam irradiations as a surrogate to quantify radiation damage. In this work we will provide examples on how small-scale mechanical testing provided deep insight into the mechanical deformation of materials after irradiation. We investigate how the properties change due the radiation induced dissolution of precipitates or due to the formation of new features such a cavities, dislocation loops or precipitates. We will highlight how the plasticity and associated mechanical property values change. Last but not least we will introduce scaling studies performed in order to extract bulk properties from small scale tests. Mesoscale mechanical tests enabled using laser fabrications are shown.

Extended Abstract:

Extensive previous work focused either on the large scale mechanical degradation of materials or nanoscale fundamental process of materials deformation. However, the mesoscale mechanics and mesoscale materials deformation has not been covered extensively due to the fact that producing samples especially from engineering materials is challenging. Conventional milling cannot be done at structures below 100um especially if damage free processing is needed. Micro EDM usually melts the surface and leads to significant microstructural changes. On the other length scale focused ion beam processing (FIB) usually takes too long in order to produce samples efficiently. Only the introduction of femto second laser ablation which has minimal heat input but allows micrometer precision. This technique

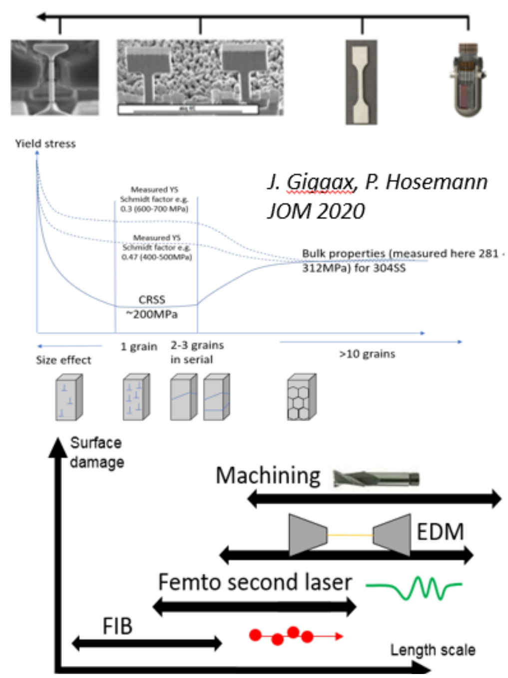

Figure 1: Illustration of multi length scale sample geometries and the the interaction between scale and microstructure. Illustration of sample fabrication methods at different length scales.

allows to manufacturing mesoscale mechanical test samples as outlined in Figure 1. Using this technique one can now study the mechanical performance of irradiated materials at truly all length scales. The presentation presents a study of multi length scale mechanical properties on HT-9 before and after irradiation. It was found that multi length scale tensile testing can reliably caried out to length scales of 50um and deliver bulk properties on this material.

However, it is important to recognize that the microstructure of the material must be known in order to allow these mechanical test samples. Therefore, a comprehensive study was performed to evaluate what microstructural features allow for reliable multi length scale mechanical testing. FeCrZr was used as a material that allows one to tune nanometer precipitates due to simple heat treatments, 304SS was used to study the effect of different grain sizes and HT-9 in different heat treatment states was used to study the effect of tempering on the mechanical testing procedure of materials. It was found that in order to obtain reliable multi scale mechanical test data on irradiated and unirradiated materials one must know the strength determining features in a material.

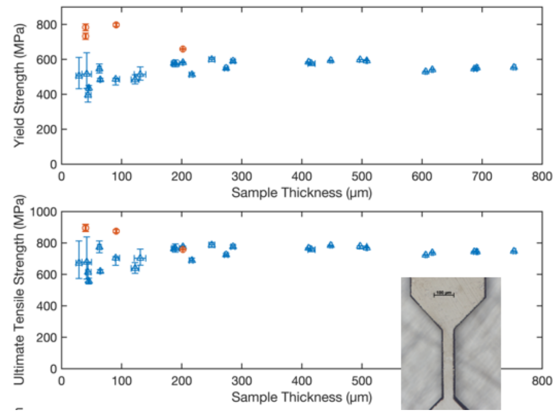

Figure 2: tensile yield stress and ultimate tensile strength on heat treated HT-9 before (blue) and after (orange) irradiation at multiple length scales.

The above discussion and work focused on strength as the key parameter since it is relevant for engineering designs. However, strain has not been tackled widely in multi scale mechanical testing. We highlight the importance of understanding the stress state when determining strain during a small-scale mechanical test. Specifically designed samples are used to evaluate the effect of geometry and materials microstructure on strain performance. This led to the development of the “block volume model” for small scale mechanical testing. Using this model strain to microstructure requirements may be derived in the future.

The concept of small-scale mechanical testing (strain and stress) will be covered especially in the context of highly irradiated materials. We will outline how these approaches can benefit the nuclear materials community and what issues one may face when working with irradiated materials.