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Shear Punch Testing on ATR Irradiated MA956 FeCrAl Alloy

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SUMMARY

The shear punch testing of irradiated and control MA956 (FeCrAl) Alloy from the NSUF-ATR-UCSB irradiation is presented. This is the first data taken on a new shear punch fixture design to test three 1.5mm punches from each 8mm x 0.5mm Disc Multipurpose Coupon (DMC). Samples were irradiated to 6.1dpa at a temperature of 315°C and 6.2 dpa at 400°C.

SHEAR PUNCH TESTING ON ATR IRRADIATED MA956 FeCrAl ALLOY

1. INTRODUCTION

MA956 has high strength and resistance to oxidation, carburization and corrosion at elevated at temperatures up to more than 1100°C. MA processing results in fine distribution of Y, Al, and O containing particles into Cr and Al rich matrix. The typical alloy composition is given in Table 1. It was first developed as an aerospace superalloy and now being used in variety of industrial applications such as gas turbine combustion chambers, advanced energy-conversion systems, etc. MA956 show improved high temperature properties compared to most Ni based alloys. In addition, due to high Cr and Al content the alloy can also be considered for accident tolerant cladding for nuclear applications. In fact, presence of fine distribution of oxide particles are proven to improve the irradiation resistance of the alloy[1]. In addition, the fine oxides can trap highly damaging transmutant helium in a fine and less harmful bubbles therefore increasing the possible use of the alloy in a variety of nuclear environments [2]. The alloy is also highly formable. It can be machined by all conventional techniques. However, conventional joining techniques produces low strength joints. Furthermore, similar to other ferritic steels the alloy shows a ductile-to-brittle transition (DBTT) at around 0-100°C. For nuclear applications involving irradiation, the high Cr is another important concern due to phase instability that results in decomposition of α- α' in these alloys. Previous tension testing of this lot of ATR irradiated MA956 showed brittle post-irradiation behavior, TEM analysis showed voids present in the as-fabricated material possibly leading to the post irradiation brittleness [3].

Table 1. Chemical composition of MA956 in wt% [4]. The balance is Fe.

	Cr	Al	Y_2O_3	Ti	Cu	Ni	C	S	Co	Mn
MA956	18.5-21.5	3.75-5.75	.3-.7	.2-.6	<.15	<.5	<.1	.007	<.3	<.3

2. EXPERIMENTAL

Thousands of Disc Multipurpose Coupons (DMC) samples were irradiated in the Advanced Test Reactor at Idaho National Laboratory as part of the ATR-NSUF-UCSB irradiation[5]. Samples were 8mm in diameter and either 0.25mm or 0.5mm thick. A shear punch jig (Fig. 1) was designed at Los Alamos National Laboratory (LANL) to generate 3 punches of 1.5mm diameter from the 8x0.5mm DMC specimens. Each punch generates both and Effective Shear Stress (ESS)-Extension curve as well as a small punch out for future microstructural analysis as well as smaller scale hardness testing. MA956 samples from capsules 7-1 and 5-2 (315°C 6.1dpa, 400°C 6.2dpa, respectively) were tested on an Instron 5567 load frame in the Wing 9 Hot Cells at LANL to generate three ESS-extension curves per sample. ESS is defined as load divided by area, where area is the circumference of the punch times the thickness of the sample. The compliance from the test system was mathematically removed from the extension data. Post test images were taken on a HIROX Digital Optical Microscope located in the hot cells.

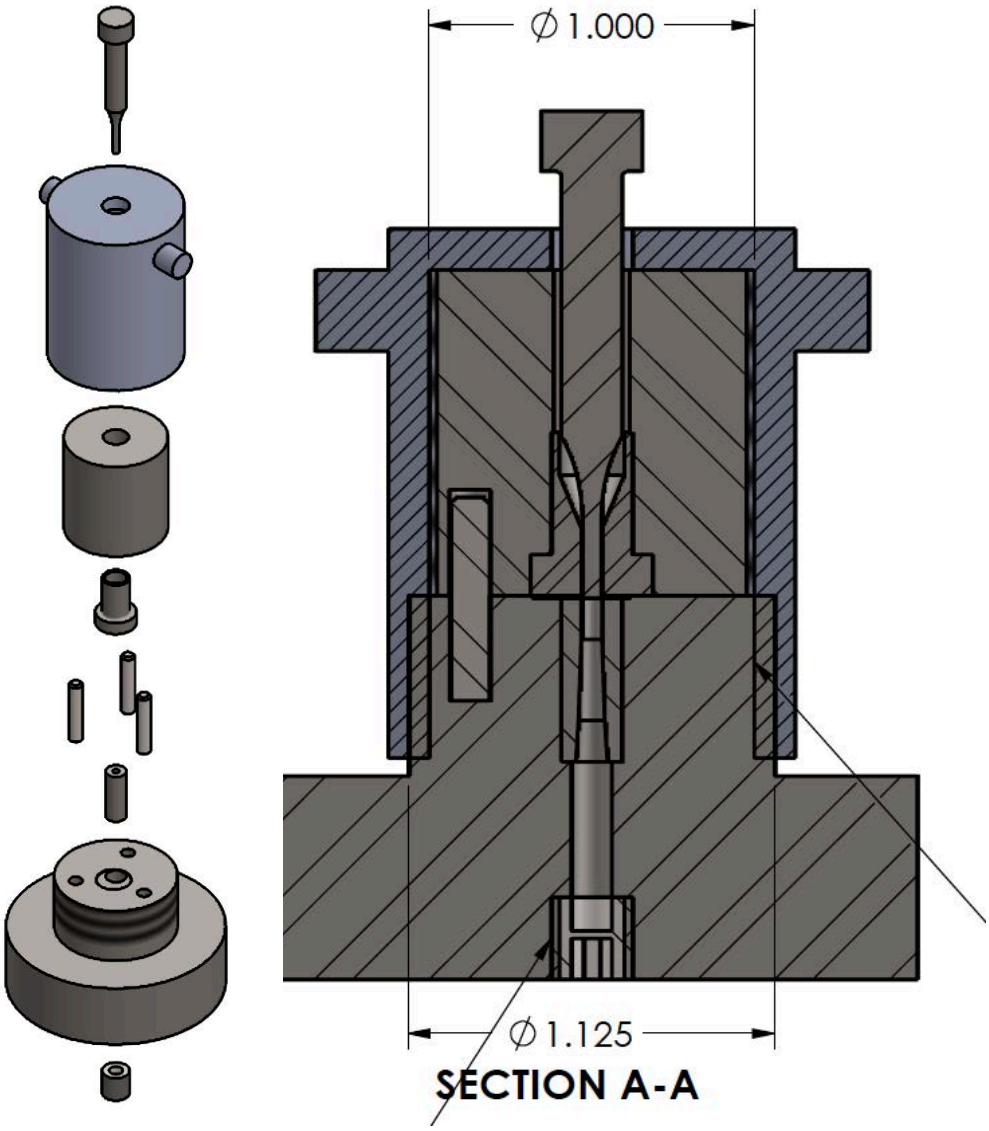

Figure 1. Schematic of 8mm DMC shear punch

3. Results

ESS vs Extension curves can be seen for initial tests on control HT9 and annealed copper in Figure 2a. These control tests show excellent repeatability for each sample. Curves for control and irradiated MA956 can be seen in Figures 2B and 3, respectively. The MA956 control test show reasonable repeatability and ductility in the as received samples. The irradiated tests show little differences between the two irradiation conditions, but there are obvious load drops (often a sign of brittleness and cracking) in the curves seen more clearly in Figure 3B.

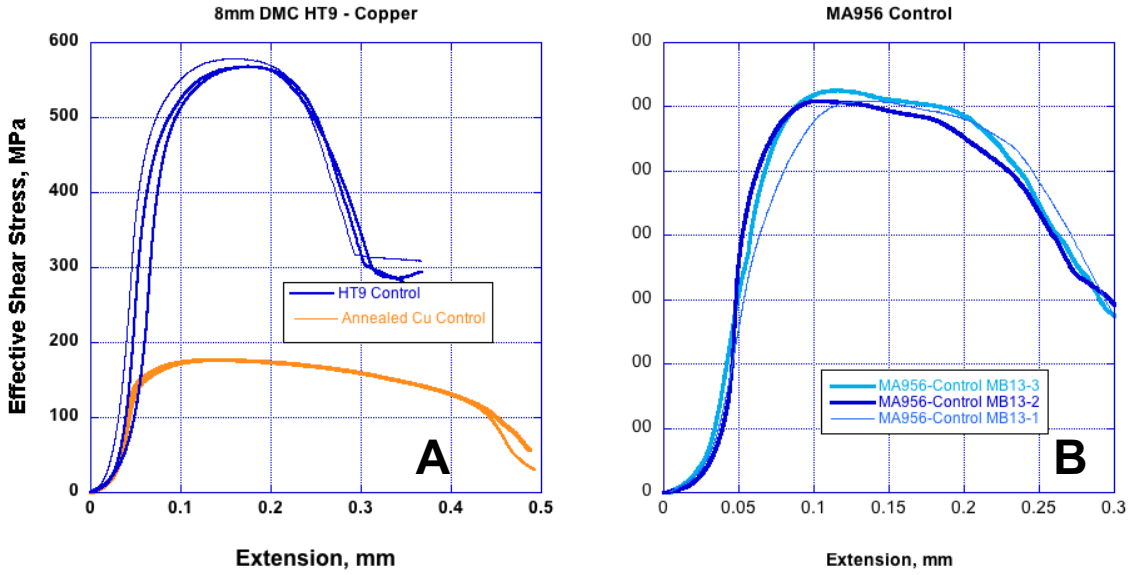

Figure 2. Control Shear Punch testing on HT9 and Copper (A) and MA956 (B).

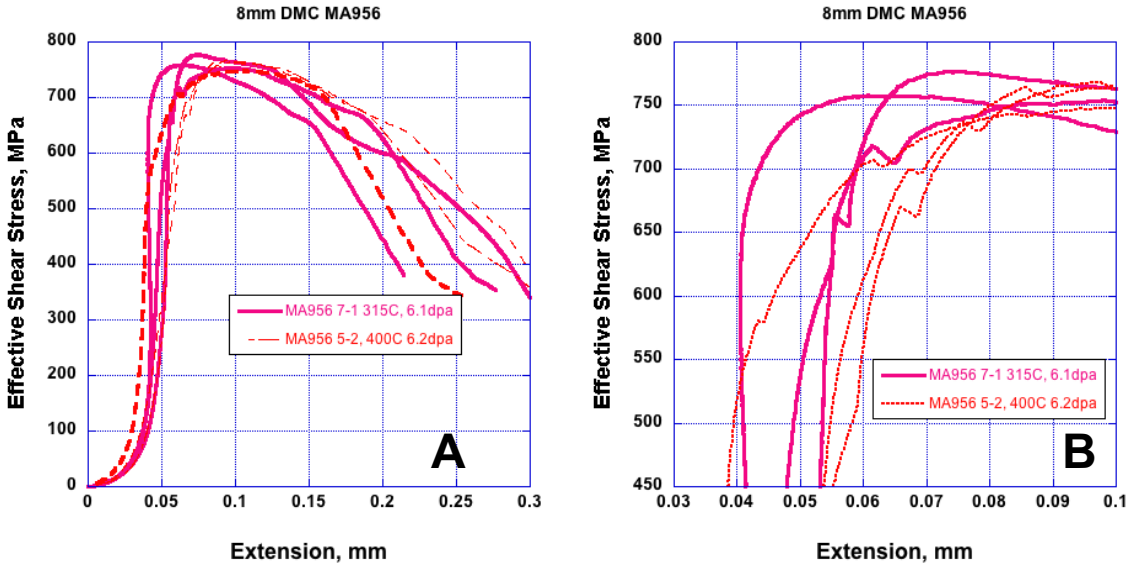

Figure 3. Irradiated Shear Punch testing on MA956, with a close up of load drops seen during testing in B.

Images of the MA956 control samples reveal nothing of particular note. The full 8mm DMC is shown in figure 4 and the 1.5mm diameter punch 1 is shown in Figure 5. However it is clear looking at the back of

the irradiated DMC (Figure 6) and punches (Figure 7) that there was cracking during the test. This was not unexpected due to the previously seen brittleness in tension tests under similar irradiation conditions [3].

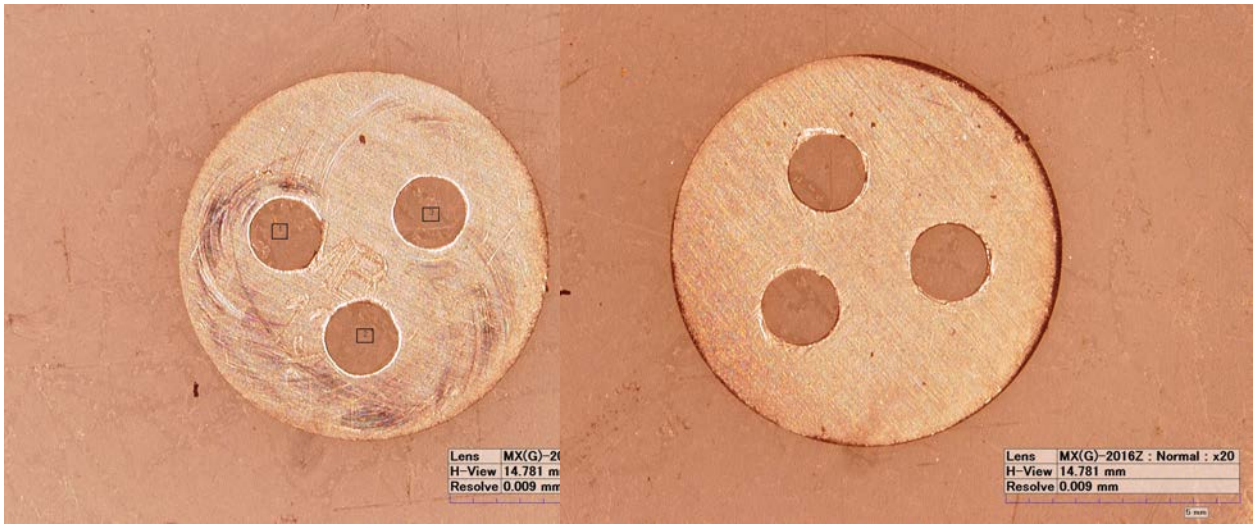

Figure 4. MA956 Control DMC. Sample is 8mm diameter imaged at 20x, and the top is seen in the left image, bottom at the right.

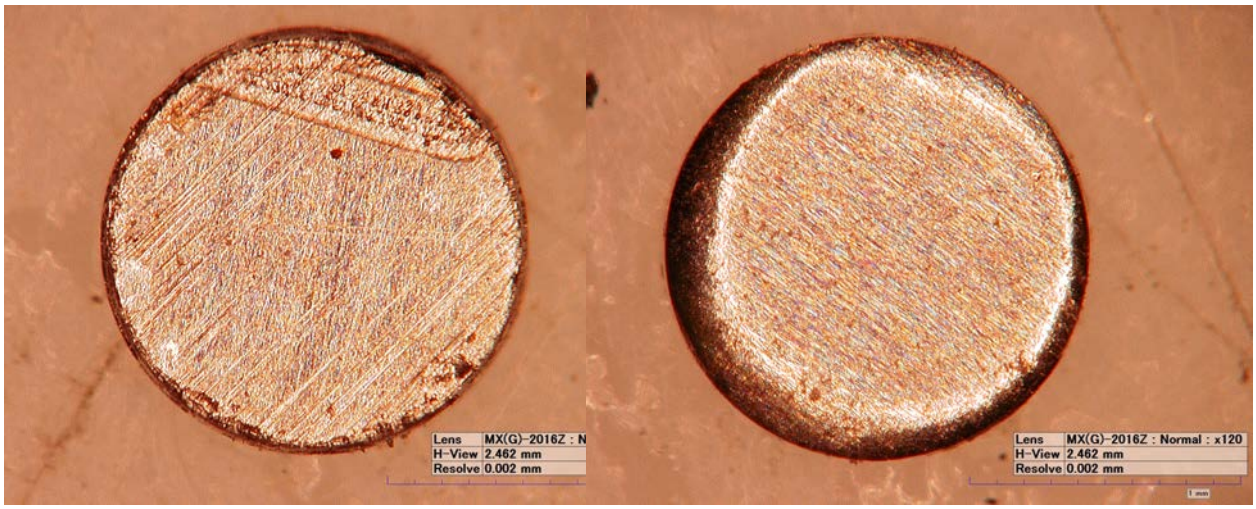

Figure 5. MA956 Control DMC punch. Sample is 1.5mm diameter imaged at 120x, the top is seen in the left image, bottom at the right.

Figure 6. MA956 Irradiated DMC, MB-18 from capsule 5-2 400c, 6.2 dpa. Sample is 8mm diameter imaged at 20x, and the top is seen in the left image, bottom at the right. Cracking can be seen around the punch holes in the right image.

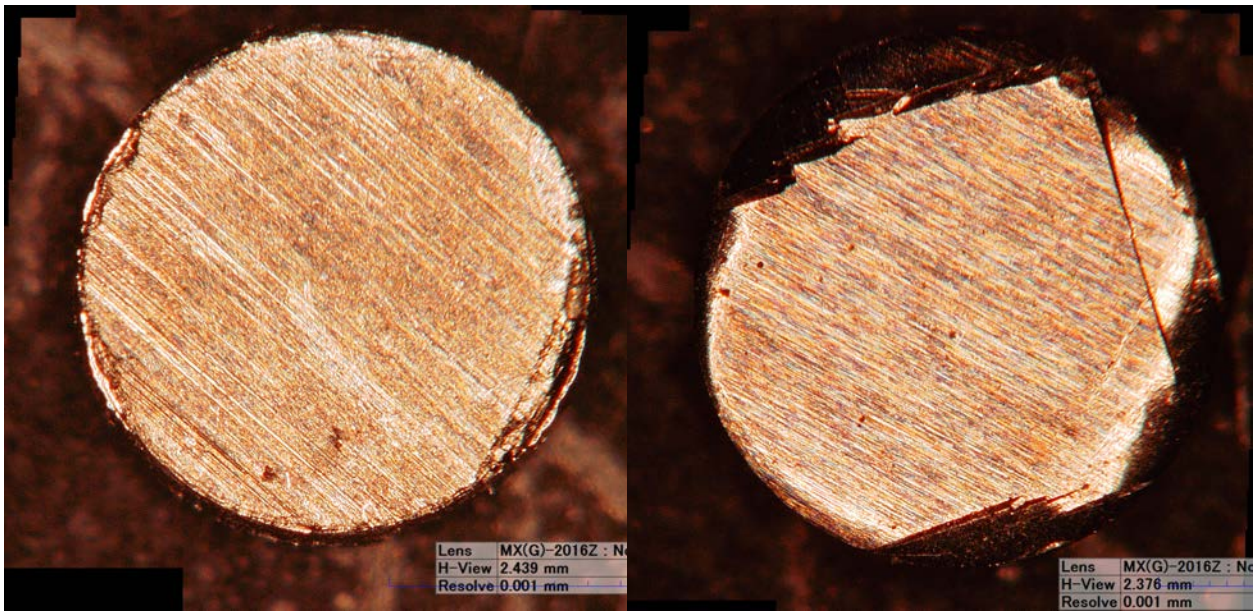

Figure 7. MA956 Irradiated punch, MB-18 from capsule 5-2 400c, 6.2 dpa. Sample is 1.5mm diameter imaged at 120x, and the top is seen in the left image, bottom at the right. Extensive cracking can be seen in the bottom of the punch.

4. Conclusions and Future Work

The shear punch test of the 8mm DMC geometry clearly shows promise for generating ESS curves as well as subsize samples in irradiated material. Repeatability is excellent for ductile control samples. The irradiated MA956 showed clear brittleness during testing, not unexpected for this alloy under these irradiation conditions. Work comparing the correlation of this shear punch geometry to the more common 3mm x 0.25mm geometry as well as to tension data is ongoing. Samples from these two irradiation capsules will also be tested and the punches will be sent to UCSB for microstructural analysis, atom probe tomography and nanoindentation. These data will feed into constitutive modeling of mechanical response in irradiated material.

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