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Shear punch tests performed using a new low compliance test fixture

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Abstract

Based on a recent finite element analysis (FEA) study performed on the shear punch test technique, it was suggested that compliance in a test frame and fixturing which is quite acceptable for uniaxial tensile tests, is much too large for shear punch tests. The FEA study suggested that this relatively large compliance was masking both the true yield point and the shape of the load versus displacement trace obtained in shear punch tests. The knowledge gained from the FEA study was used to design a new shear punch test fixture which more directly measures punch tip displacement. The design of this fixture, the traces obtained from this fixture, and the correlation between uniaxial yield stress and shear yield stress obtained using this fixture are presented here. In general, traces obtained from the new fixture contain much less compliance resulting in a trace shape which is more similar in appearance to a corresponding uniaxial tensile trace. Due to the more direct measurement of displacement, it was possible to measure yield stress at an offset shear strain in a manner analogous to yield stress measurement in a uniaxial tensile test. The correlation between shear yield and uniaxial yield was altered by this new yield measurement technique, but the new correlation was not as greatly improved as was suggested would occur from the FEA study.

1. Introduction

The shear punch test is a small specimen test technique for estimating uniaxial tensile properties from a transmission electron microscopy (TEM) disk [1–6] (and other sheet stock geometries). A 1 mm flat-faced punch is driven through a TEM disk at a constant rate. In the past, some researchers, including the present authors, have assumed that crosshead displacement could adequately represent punch tip displacement, and the load has been plotted as a function of crosshead displacement. The resulting load versus crosshead displacement trace has many features common to a uniaxial tensile test including a region of linear loading, a yield point, a region of work hardening (or work softening), and an ultimate load [1,2]. Loads are converted to an effective shear stress by dividing by $2\pi rt$ where r is the average of the punch and receiving die radii, and t is the thickness of the specimen. The effective shear yield, defined as the point of deviation from linear loading, correlates well with uniaxial yield stress for a variety of materials as shown in Fig. 1. Also, the effective shear ultimate stress correlates well with the uniaxial ultimate strength [2], and true uniform elongation can be correlated with shear punch test data [3].

Recent development of the shear punch test technique has focused on understanding the nature of the slope and intercept of the correlation between uniaxial yield and effective shear yield [7] as well as on identifying ways to reduce the material-to-material scatter in the correlation between uniaxial yield and effective shear yield [8]. Most recently, finite element analysis (FEA) was used to show that the compliance of test machines which are typically used for tensile tests and the previously used shear punch

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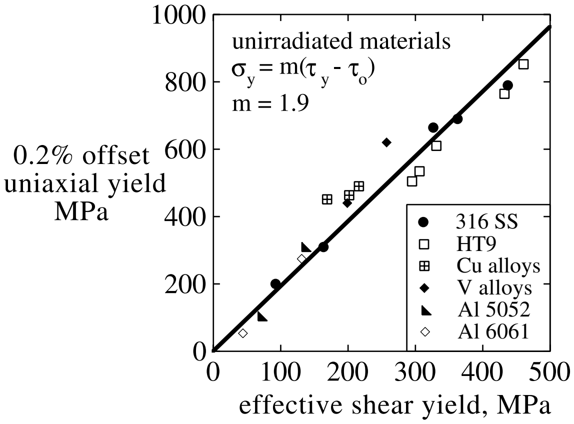

Fig. 1. A past correlation between uniaxial yield and shear yield when measuring yield at deviation from linearity using an older shear punch fixture where displacement was measured at the crosshead.

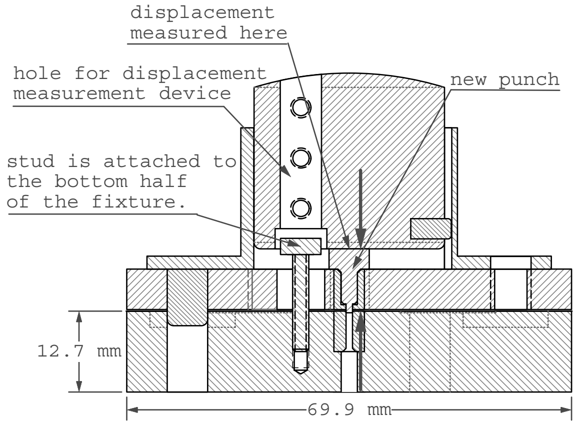

Fig. 2. New shear punch fixture. Capacitive based displacement measurement probe measures its position relative to the top of the stud. The thick arrows indicate the approximate displacement measurement reference points.

fixture is much greater than the elastic compliance of a TEM disk when shear punch tested [8]. The FEA work suggested that a large test machine compliance would obscure detail which is present when load is plotted as function of punch tip displacement. The FEA work also suggested that the correlation between uniaxial yield and shear yield would be improved if yield on a load versus punch tip displacement trace was measured at an offset shear strain in a manner analogous to measuring yield on a uniaxial tensile trace.

In the present work, the predictions from the FEA simulations were tested using a new shear punch fixture which was designed to have reduced compliance and measure displacement at a location much closer to the punch tip.

2. Experimental

A schematic of the new shear punch fixture is shown in Fig. 2. The key changes are the new punch and the introduction of a displacement measurement device. The new punch is estimated to be approximately 8 times stiffer than previous punches which were simply a 1 mm diameter pin approximately 18 mm in length. Displacement was measured using a capacitive-based displacement measurement device (CDMD). The 'stud' shown in Fig. 2 is attached to the bottom half of the fixture, and serves as the reference point for the CDMD. As the CDMD is located inside of the 'button', the CDMD roughly measures the displacement of the top of the punch relative to the surface on which the specimen rests, and therefore, contributions to test device compliance come mainly from the punch. The FEA simulations tracked the position of the punch tip relative to the surface on which the specimen rests, and thus the real system has a greater amount of compliance than in the FEA simulations.

Materials and thermomechanical treatments used in this study are shown in Table 1. All specimens were fabricated by EDM from approximately 0.25 mm thick sheet stock. Three shear punch tests and two tensile tests were performed per each unique combination of material and thermomechanical treatment.

The punch used for the testing had a tip diameter of 0.98 mm while the receiving hole diameter was 1.04 mm. This gives a clearance, w, of 0.32 mm which is slightly larger than the previously used value of 0.25 mm. The initial shear strain rate, as calculated from

$$\dot{\varepsilon}_{rz} = \frac{1}{2}\frac{\dot{x}}{w}, \tag{1}$$

where $\dot{x}$ is the punch displacement rate, was approximately 4×10^{-3} s^{-1}. The factor of 1/2 in Eq. (1) results from converting the shear strain to an engineering shear strain. [1] Displacement was simultaneously measured at the CDMD and at the crosshead. Load was converted to an effective shear stress by dividing by $2\pi rt$. Based on the FEA work [8], a 1.0% offset shear strain was used as the point at which shear yield was measured in the punch displacement traces. For the crosshead displacement traces, yield was measured at deviation from linearity as it has been done in the past.

The S1 tensile geometry (1.2 mm gage width, 5 mm gage length) was used for the tensile specimens. The initial strain rate was approximately 1×10^{-4} s^{-1}. Dis-

[1] $\varepsilon_{rz} = \varepsilon_{zr} = 1/2(\gamma_{rz} + \gamma_{zr})$, $\gamma_{rz} = x/w$, $\gamma_{zr} = 0$.

Table 1
Materials examined for this study and their thermomechanical treatments

Alloy class	Alloy	Thermomechanical treatment
Al alloys	5000	0 (solution annealed), H38 (aged and cold-worked)
	6061	0 (solution annealed), T6 (aged)
Stainless steels	316 SS	Two different age and cold-work treatments
	HT9	Two different tempering treatments
Low carbon steel	1010	SA, CW
Brass	CDA-260	SA, CW
Cu alloys	$CuHfO_2$	Cold-worked
	MZC3	Precipitation strengthened

placement was measured at the crosshead. Yield was measured at a 0.2% offset strain.

3. Results and discussion

3.1. Comparison of traces

Comparative traces for two of the materials which were examined are shown in Figs. 3 and 4. Fig. 3(a) shows a comparison of a punch displacement trace and a corresponding crosshead displacement trace for the solution annealed 1010 steel. The slope of the linear portion of the punch displacement trace is approximately four times steeper than the crosshead displacement trace. Both traces have similar features, but the additional compliance in the crosshead trace leads to a different curvature. The shear punch traces can be compared to the corresponding tensile trace which is shown in Fig. 3(b). As can be seen, the punch displacement trace (and the crosshead displacement trace) have all the same features found in the tensile trace, including a yield point and a Lüders plateau. The shear punch traces do show significantly greater work hardening though. Figs. 4(a) and (b) show a comparison between shear punch tests traces and a tensile test trace of Al 5000-H38 aluminum alloy. As with the 1010 steel, the shear punch traces of the Al 5000-H38 alloy have the same features found in the corresponding tensile traces, including the strain serrations. And in this case, the punch displacement trace is very similar in overall appearance to the tensile trace. In general, punch displacement traces had a strong similarity to corresponding tensile traces when the uniform elongation was relatively low. This trend can be understood by considering that in a shear punch test, reduction in load bearing area is increasingly controlled by cutting of the material as punch displacement becomes very large. Thus, for materials which display low uniform elongation, reduction in loading area is probably most strongly controlled by the same processes which control it in a tensile test.

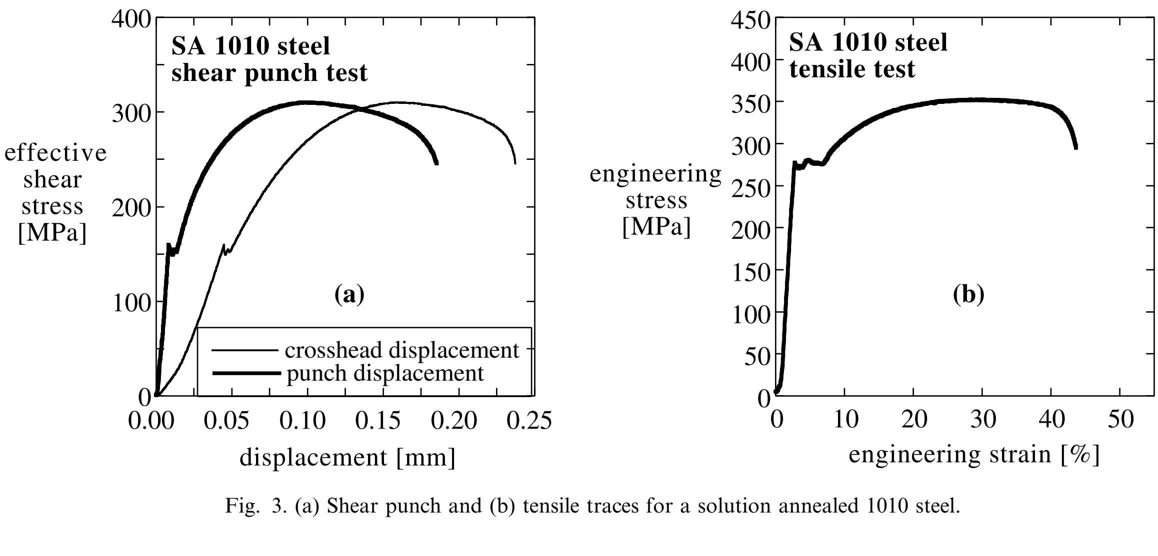

Fig. 3. (a) Shear punch and (b) tensile traces for a solution annealed 1010 steel.

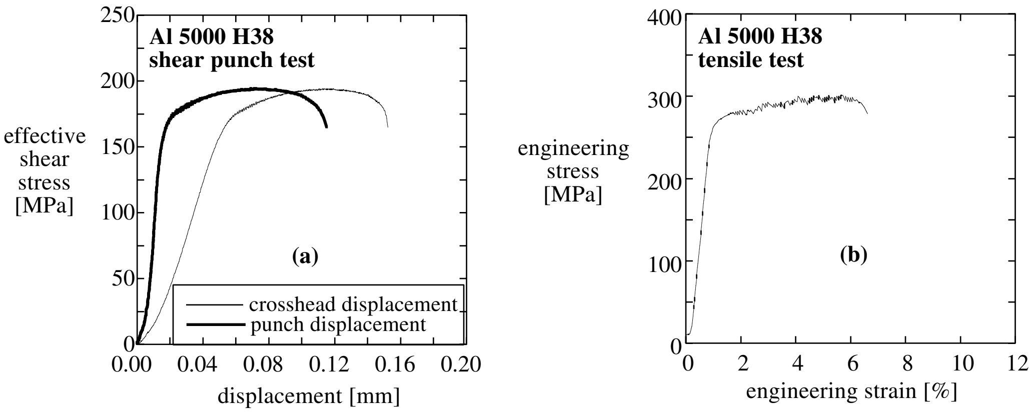

Fig. 4. (a) Shear punch and (b) tensile traces for Al 5000-H38. Note that strain serrations are present in the shear punch test traces.

3.2. Comparison of correlations

Correlations between uniaxial yield and shear yield obtained from either crosshead displacement traces or punch displacement traces are shown in Figs. 5(a) and (b), respectively. Based on the prior FEA work, it was expected that there would be a significant difference in the correlations with the punch displacement-based correlation being much tighter. However, the difference in the correlations is not great. The general effect of measuring yield from the punch displacement traces was to reduce the shear yield values and thus 'rotate' each individual material correlation clockwise. This led to a tighter correlation at lower yield stresses and a slightly looser correlation at higher yield stresses. The result is that the scatter in the punch displacement-based correlation is now roughly proportional to the magnitude of the yield stress.

4. Summary and conclusions

Reducing shear punch test fixture compliance and more directly measuring punch tip displacement has several beneficial effects. First, it provides a more accurate measure of the amount of deformation that is occurring during a shear punch test. This, in turn, has led to shear punch test traces which have a very strong similarity to corresponding tensile traces. A more accurate measure of the punch tip displacement also makes

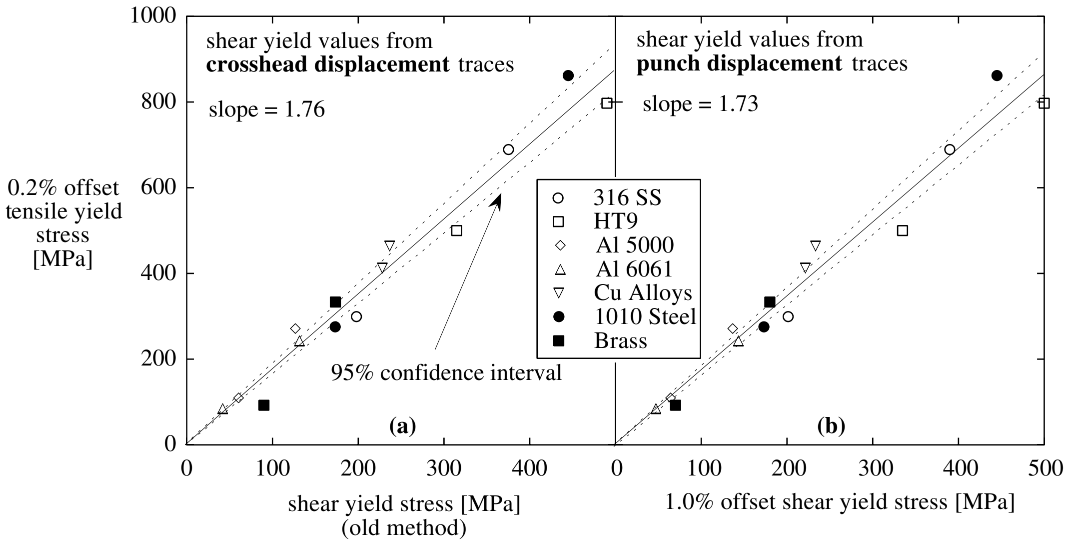

Fig. 5. Correlation between uniaxial yield and shear yield for (a) deviation from linearity on crosshead displacement traces and (b) 1.0% offset shear yield on punch displacement traces.

it possible to associate a shear strain value with the displacement data at the onset of plastic deformation which has made it possible to measure shear yield at an offset shear strain. Measuring shear yield at an offset shear strain is useful because it provides an unambiguous means for determining the shear yield, and it is more directly comparable to uniaxial yield stress values measured at an offset strain. Finally, by measuring shear yield at a 1.0% offset shear strain on punch displacement traces using this improved fixture, the correlation between uniaxial yield and shear yield is somewhat improved at lower yield values.

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