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Kolsky Tension Bar Techniques for Dynamic Characterization of Alloys

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Dynamic stress-strain response associated with damage and failure mechanisms of alloys is desired to be quantitatively determined. Dynamic tensile characterization has been demonstrated an efficient method for such an investigation. However, reliable dynamic tensile characterization relies on appropriate experimental instruments and procedure. In this study, we employed a newly developed Kolsky tension bar to characterize the tensile properties of alloys [1, 2]. Challenges and remedies in the dynamic tensile characterization with the Kolsky tension bar are presented.

At 2010 SEM Annual Conference, we presented the Kolsky tension bar developed at Sandia National Laboratories, California. This new Kolsky tension bar facilitates reliable loading and easy pulse shaping. An additional laser-beam measurement system is employed to directly measure the displacement of the incident bar end such that the specimen deformation is able to be accurately measured. However, for a dumbbell specimen threaded into the bar ends, the specimen strain is measured in terms of average strain over the specimen length inclusive of the transition portion from the threads to the gage section. The actual strain over the specimen gage length needs to be corrected. In addition, it is desirable for the specimen to deform uniformly such that the average strain can represent any point wise strain over the specimen gage section. The uniform deformation, which is usually associated with stress equilibration, needs to be verified. An abnormal stress peak was also observed in the stress response of 4340-V steel, as presented at 2010 SEM Annual Conference [1]. The stress peak needs to be properly addressed in order to obtain reliable tensile stress-strain response of alloys.

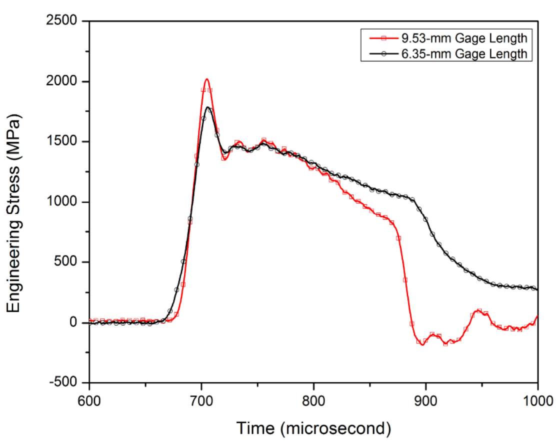


Fig. 1. Stress in the specimens with different gage lengths

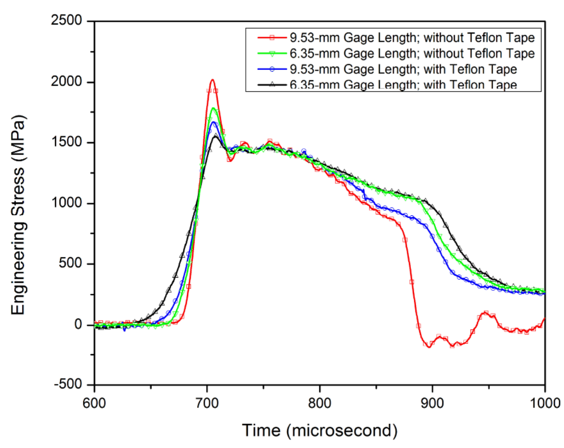


Fig. 2. Comparison of stress in the specimens with and without Taflon tape applied

We firstly address the abnormal stress peak. An early stress peak, which occurs around plastic yielding, has been commonly observed in dynamic tensile characterization of alloys with Kolsky tension bars. However, different interpretations have been presented in regard to the mechanism of the stress peak [3, 4]. In this study, we used a 4330-V steel as an example to determine the effects of specimen length and installation on the amplitude of the stress peak in Kolsky tension bar experiments. Figure 1 shows the stress histories in the specimens with two different gage lengths (6.35 and 9.53-mm-long) at an identical strain rate of approximately 1100 s^{-1}. It is observed that the amplitude of the peak stress was reduced by 12% when the specimen gage length was reduced from 9.53 mm to 6.35 mm. In order to facilitate the same strain rate on the specimens, the longer specimen requires higher impact energy by means of higher impact speed of striker. When the contact between the specimen and the bar ends is not perfect, additional impact, i.e., between the thread teeth on the specimen and bar ends, may be generated. The higher impact speed amplifies such an effect of imperfect contact. To confirm this, Teflon tape was applied on the threads of both the specimen and the adaptors. Figure 2 clearly shows that the amplitude of the peak stress was significantly reduced after the Teflon tape was applied. This also confirms that the stress peak observed in the Kolsky tension bar experiments is pseudo, which should be eliminated. Applying Teflon tape has been demonstrated an efficient method to minimize the amplitude of the peak stress.

After the pseudo stress peak is minimized, the stress histories measured with the strain gages on the transmission bar becomes a reliable representative of actual stress response in the specimen. However, the stress over the entire specimen gage length should be equilibrated. In other words, the specimen should deform uniformly. Due to the complication of the tension bar system,

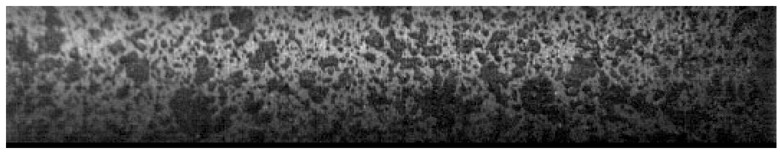
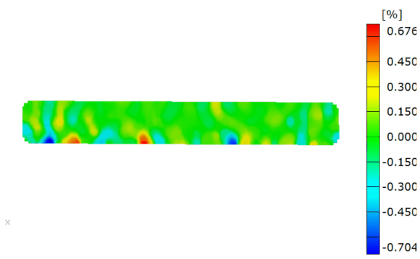
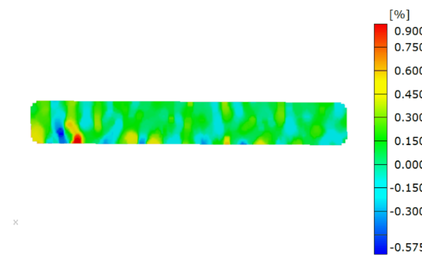


Fig. 3. DIC pattern on the specimen surface

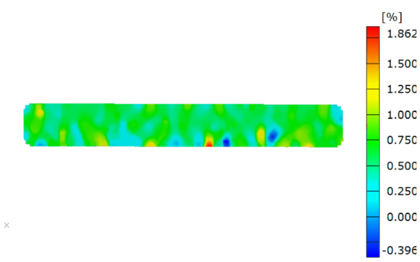


T=0

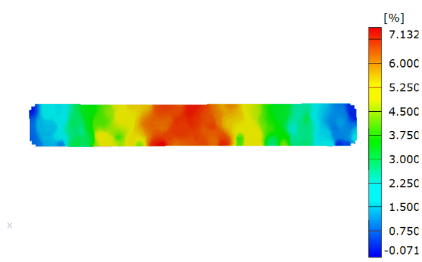
T=12 μs



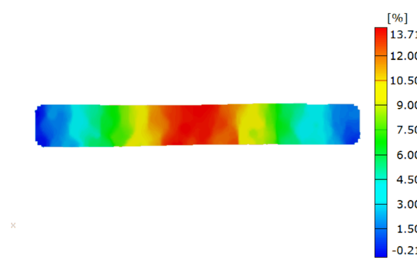
T=24 μs



T=60 μs



T=120 μs



T=180 μs

Fig. 4. Specimen axial deformation (E_{xx}) from DIC analysis

the reflected pulse may not be reliable to calculate the stress at the front end of the specimen with classic "2-wave" method. In this study, we employed digital image correction (DIC) to the specimen to measure the deformation field over the specimen gage length. Figure 3 shows the DIC pattern on the specimen surface. The DIC pattern was photographed with a Phantom V12.1 digital camera at the speed of approximately 83,000 frames per second. Figure 4 shows the DIC results during the tensile loading. Figure 4 clearly indicates that the specimen has already achieved uniform deformation within the first 12 μs. A significant strain localization was not observed until t=120 μs (Fig. 4). This strain localization became more and more severe until macroscopic visible necking is observed. Based on the DIC results, the specimen deformed uniformly before necking occurred. Therefore, the signal from the strain gages on the transmission bar can be used for calculating the stress history in the specimen. The DIC results can be used for the strain history in the specimen. However, the limited number of data points from the DIC results may not yield accurate stress-strain response of the specimen under investigation.

In this study, we incorporated laser-beam measurement and direct strain-gage measurement on the specimen surface, as presented in Ref. [5], to calculate the specimen strain history. Since the laser-beam measurement provides only displacement information, the effective specimen gage length needs to be determined for accurate calculation of specimen strain. Figure 5 shows the mechanical drawing of the steel specimen. When the specimen is subjected to mechanical loading, the total deformation includes the deformation on not only the gage section but also the transition (non-gage) section. The portion of the displacement over the non-gage section to the total specimen displacement is not negligible when the specimen is under elastic deformation. Direct strain-gage measurement on the specimen gage section compensates this obstacle. The strain gage on the specimen is able to measure the specimen strain up to 2%. The specimen strain over 2% can be calculated with the laser-beam system presented in [1, 2]. However, the displacement on the non-gage section should be deducted from the total displacement measured with the laser-beam system. It is noted that, in this study, with increasing load on the specimen, the gage section will enter into plasticity while the non-gage section still remains in elasticity. In this case, the displacement on the non-gage section is approximated to a constant of 0.0178 mm (or 0.0007 inch) if the specimen, specified in Fig. 5, is assumed to have a perfectly plastic response with a yield strength of 1400 MPa. This non-gage-section displacement has been deducted from the laser-beam measurement for calculating the plastic strain of the specimen in this study.

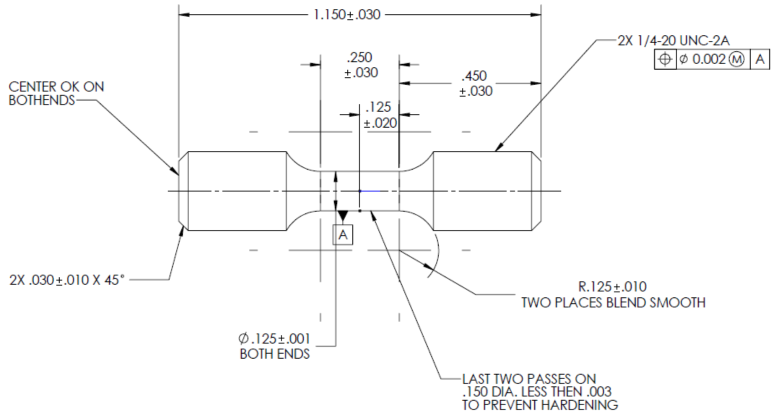


Fig. 5. Mechanical drawing of the tensile specimen

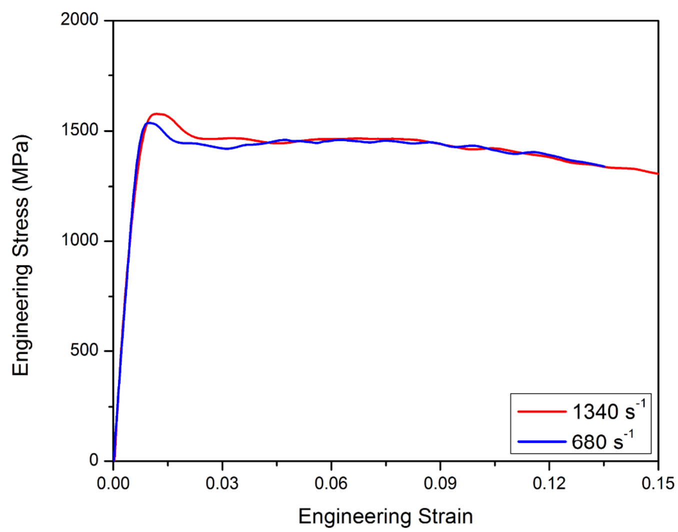


Fig. 6. Dynamic tensile stress-strain curves of 4340-V steel

Based on above analysis, dynamic tensile stress-strain curves of 4330-V steel were obtained at two different strain rates, 1340 and 680 s^{-1}. Figure 6 shows the mean curves of three identical experiments at each strain rate. Again, it is noted that the specimen strain was obtained directly from specimen strain gage measurement when it is smaller than 2%; while the strain larger than 2% was obtained from laser-beam measurement after proper correction. The pseudo early stress peak was minimized but not fully eliminated, as shown in Fig. 6. The 4330-V steel shows little difference in tensile stress-strain response at 680 and 1340 s^{-1}. However, the flow stress at both dynamic strain rates significantly increases in comparison with that at quasi-static strain rates.

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