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User case study: multi-scale impact testing to study high-strain rate deformation

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Overview

Strain rate and deformation size are two significant factors affecting the mechanical responses of most crystals, which usually show greater strength at high strain rate or at micro length scale. The high-strain-rate deformation has been widely studied using macro impact techniques. Small-scale deformation can be achieved by micro-pillar, micro-tensile and nanoindentation tests. However, equipment to achieve high-velocity impact at nano- or micro- length scale has been lacking, leading to limited understanding of the deformation behaviour and mechanism under high strain rate at small scales. This presents a challenge in designing impact-resistant materials, which are needed for extreme impact applications such as high-speed collisions of solid particles with jet engine turbine blades.

The NanoTest impact module maintains the nanometre resolution of nanoindentation and achieves the high strain rate (>10^3 s^{-1}) by a pendulum system. The single impact mode can be used to analyze the impact deformation from nano- to micro- length scales. The multi-cycle impact at the same position can indicate the damage accumulation during repeated impacts. The random impact mode can simulate the macro damage from a number of small-scale impacts. Such tests provide data to facilitate the design of next-generation impact-resistant materials. With the help of micromachining and characterization, such as focus ion beam milling (FIB) and transmission electron microscope (TEM), the origin and evolution of impact damage can be determined, which is crucial in failure analysis, modelling and performance prediction.

SEU NanoTest platform configuration

- Berkovich, Vickers, Cube Corner and Conical indenters.
- Optical microscope (up to 40x magnification).
- Load and depth-controlled mode.
- NanoTest Pendulum Impulse Test Module.
- Covers range forces from 0.1 mN to 500 mN.

Multi-scale impact experiment

The NanoTest Vantage has been used to perform muti-scale impact on CoCrNi-based medium entropy alloy. The nano-impact tests were carried out at a range of applied loads (5-40 mN) using a calibrated Berkovich diamond indenter impacting at 90° to the surface accelerating from 10 µm above the initial surface. Micro-impact tests were performed at a range of applied loads (250-3000 mN) with an accelerating distance of 40 µm.

Increasing impact loads lead to higher depth and crater area. Figure 1 shows the morphology of residual craters at a range of applied loads (5-3000 mN) with depths ranging from hundreds of nanometers to tens of microns indicating deformation across length scales.

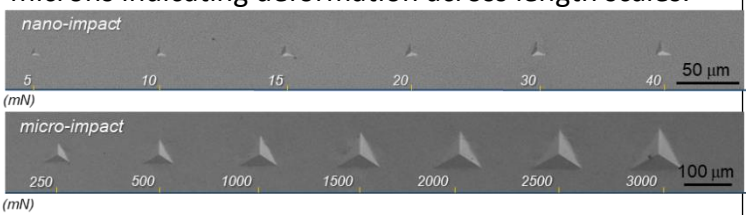

Figure 1. SEM images of residual crater after multi-impact tests.

Cross-sectional TEM images of the deformed zone below the craters strengthen the comparison of size effect on impact deformation, as shown in Figure 2. At small impact loads of 20 mN, the deformation is dominated by twins and stacking faults. At a medium load 40 mN, stacking faults and short-range dislocations are observed.

In contrast, at high load (500 mN), long dislocations are found. In multi-scale impact tests, the materials show a different high strain rate deformation mechanism.

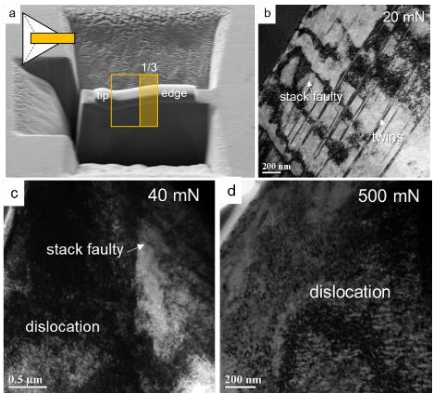

Figure 2 a. FIB-SEM image of the cross-section on the crater; b-d. TEM images of deformed microstructures at 20 mN, 40 mN and 500 mN applied impact loads.

User Profile

Prof. Chen's group has many years' experience in the design, analysis, modelling and application of instrumented nanoindentation and nano-impact technique. The team has worked with Micro Materials Ltd. to apply such NanoTest platform in the study of metal deformation mechanism [1-4] and impact-fatigue phenomena [5-7]. The group is part of the Materials Science School at Southeast University, with its analytical and testing centre including two NanoTest platforms combining the nanoindentation, nanoscratch and nano-impact capabilities, as shown in Figure 3. Further capabilities for sample preparation and microstructural characterization (FIB milling, TEM, electron back-scattered diffraction, etc) enable the in-depth analysis of deformation mechanisms in nano-/micro-mechanical testing and provide the theoretical evidence to support the design of new generation materials.

Figure 3. SEU NanoTest platform.

Webpage:
https://smse.seu.edu.cn/2011/1225/c2590a83609/page.htm

Highlights from the user

- Nano-impact and micro-impact tests can simulate the extreme loading service including the high strain rate and small deformed size.
- Multi-scale deformation achieved by tuning the impact applied load and accelerating distance.
- The combination of multi-scale impact and structural characterization reveals the size-related mechanism of high-strain-rate deformation.

Quote from the user

"The nano-impact and micro-impact tests pave the way for the knowledge of origin and evolution of impact damage"

References

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