Application Note

Impact Hardness

Indentation, High Strain Rate and High-Speed Data Acquisition using DataBurst Technology

Introduction

The strength or hardness of a material is a function of composition, processing, temperature, and strain rate. Traditional mechanical testing, e.g., tensile testing or microhardness, is performed at quasi-static strain rates on the order of 1×10^{-3} to $1 \times 10^{-1} s^{-1}$. At higher strain rates, materials typically become stronger and harder but lose ductility and toughness. It is important in many applications to characterize the strength of materials at high strain rates, but these experiments can be challenging and expensive. Impact testing is a convenient method for investigating high strain rate behavior, but there is a need for accurate and precise data collection. Here, we combine the precision and accuracy of the Nano Indenter® G200X with force-controlled impact testing using the proprietary DataBurst option. DataBurst enables data acquisition at a rate of 100kHz, or one data point every 10μs, enabling the measurement of indentation strain rates up to $1 \times 10^{4} s^{-1}$. Hardness measured at these high strain rates is directly comparable to quasi-static hardness measurements using the same sample and experimental setup.

Experimental Method

A Nano Indenter G200X equipped with an InForce 50 actuator and a diamond Berkovich indenter was used to perform indentation testing on the following materials: aluminum alloy 1100, commercial purity BCC Iron, 316 stainless steel, and commercial purity magnesium. Here, we focus on the results from ISO 14577, Constant Load and Hold (CLH), and impact indentation testing by generating hardness comparisons as a function of indentation strain rate. ISO 14577 is an international standard for nanoindentation testing and the details of that experiment as well as the CLH test can be found in the indentation literature and other application notes from KLA[1,2]. The impact hardness test methodology is described in Figure 1.

An indenter retraction distance of 6μm and a step force of 6mN was used to create the impact experiment. The key parameters measured from the impact hardness experiments are indentation depth h, indenter velocity $\dot{h}$, and applied load P. The indentation depth and the area function describing the tip geometry are used to calculate the contact area A. These parameters are then combined to determine the hardness H and the indentation strain rate $\dot{\epsilon}$:

$$H = \frac{P}{A} \tag{1}$$

$$\dot{\epsilon} = \frac{\dot{h}}{h} \tag{2}$$

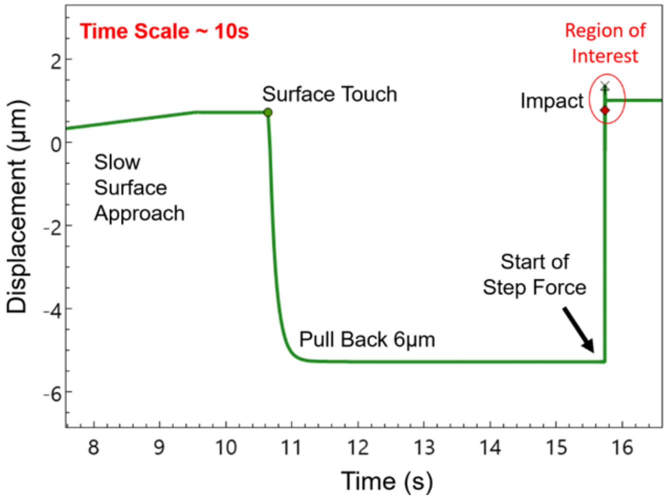

Figure 1. The impact hardness test methodology is comprised of a slow surface approach, a low load surface touch, indenter retraction (pull back), a step force command and surface impact.

Impact Testing Results

Here, we focus on the results from impact tests on commercial purity magnesium. An indenter retraction distance of 6μm and a step force of 6mN resulted in an indenter velocity of nearly 20mm/s at contact and a dynamic load of 50mN, due to the deceleration of the indenter mass to zero velocity over ~130μs. While the entire experiment lasts 10s, the impact loading and unloading event is ~200μs. Impact results on the magnesium are shown in Figure 2 and Figure 3 for velocity and load as a function of time and indentation depth, respectively.

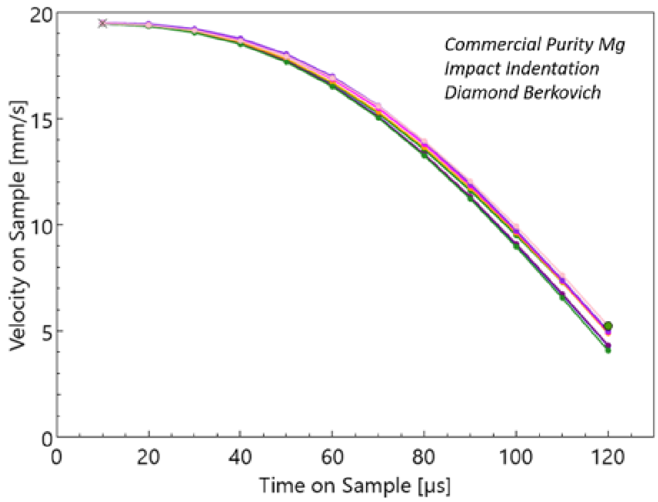

Figure 2. Impact hardness velocity as a function of time for commercially pure Mg.

Indenter velocity and depth combined with applied load determine the hardness and indentation strain rate. These parameters can be plotted on a log plot with the assumption of power-law creep behavior[3] for comparison to the more quasi-static results from ISO 14577 and the CLH indentation techniques, as shown in Figure 4 for commercial purity polycrystalline magnesium.

Nanoindentation impact testing combined with quasi-static testing generates hardness measurements over nearly eight orders of magnitude of indentation strain rate. There is a noticeable change in the slope between strain rate and hardness between the quasi-static and impact testing, suggesting the possibility of a different mechanism for plastic deformation. Average impact hardness results for the other metals tested in this study are shown in Table 1.

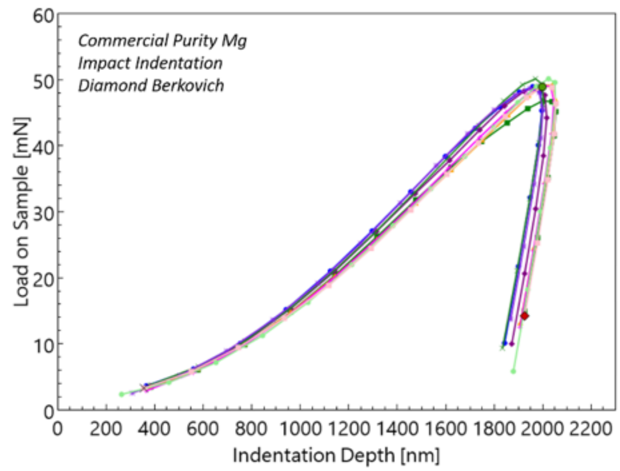

Figure 3. Impact hardness load as a function of indentation depth for commercially pure Mg.

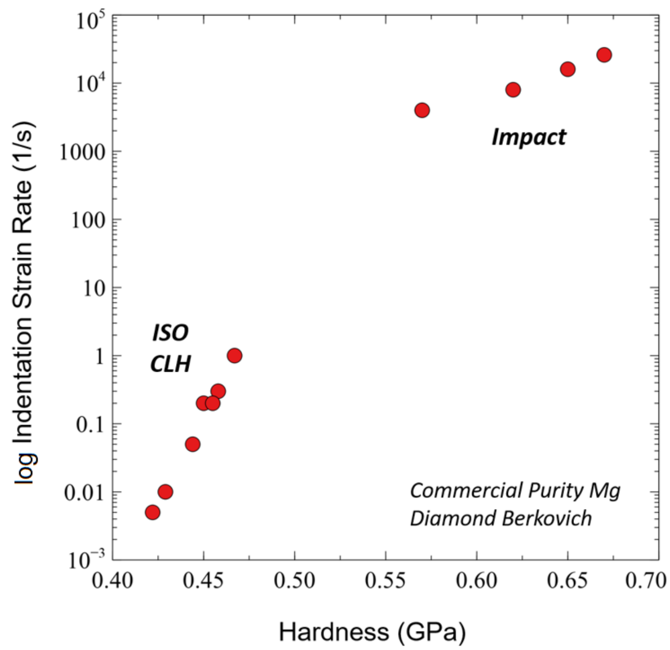

Figure 4. Strain rate as a function of hardness for commercially pure Mg.

Advantages of KLA Nanoindenters for Impact Testing

- KLA nanoindenters provide force-controlled experiments with an independent displacement measurement.
- KLA actuators act as single harmonic oscillators, which simplifies the calculations of load and velocity using knowledge of the mass, stiffness, and damping of the system.
- Fast data acquisition rates are essential for fully characterizing the ~200μs impact experiments. The DataBurst option allows for capturing data at 100kHz.

Table 1. Impact Hardness of Metals Tested with the Nano Indenter G200X

Material	Average Impact Strain Rate (s^{-1})	Average Impact Hardness (GPa)	Average Quasi-static Hardness (GPa)
Al 1100	$2.4x10^3$	0.59 ± 0.02	0.55 ± 0.01
BCC Iron	$6.0x10^3$	3.3 ± 0.1	2.1 ± 0.2
316 Stainless Steel	$7.4x10^3$	6.7 ± 0.2	4.9 ± 0.3

Summary

Impact hardness measurements at high strain rates on the order of $1x10^4 s^{-1}$ are possible with KLA nanoindenters using DataBurst technology. The impact test, combined with (a) quasi-static constant load and hold and (b) constant loading rate experiments, allows the measurement of hardness over eight orders of magnitude of indentation strain rates at a given temperature. A clear, measurable difference in hardness was measured for commercial purity, polycrystalline magnesium as a function of indentation strain rate.

References

1. ISO (2015). ISO 14577-1:2015, "Metallic materials – instrumented indentation test for hardness and materials parameters – Part 1: Test method."
2. P. Sudharshan Phani and W. C. Oliver, Acta Materialia 111 (2016) 31-38.
3. Dieter, George E., Mechanical Metallurgy, 1988.

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