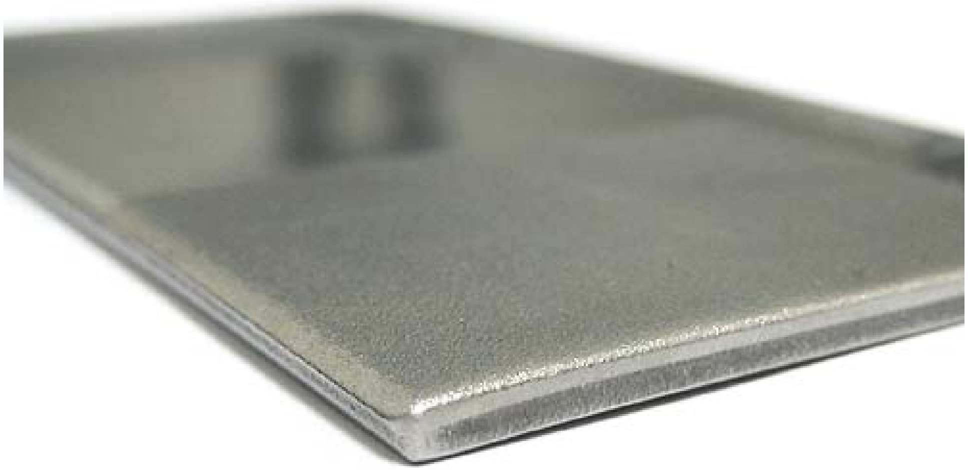
NANOVEA®
A Better Measure.

SHOT PEEN HARDNESS
WITH NANOINDENTATION



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INTRO

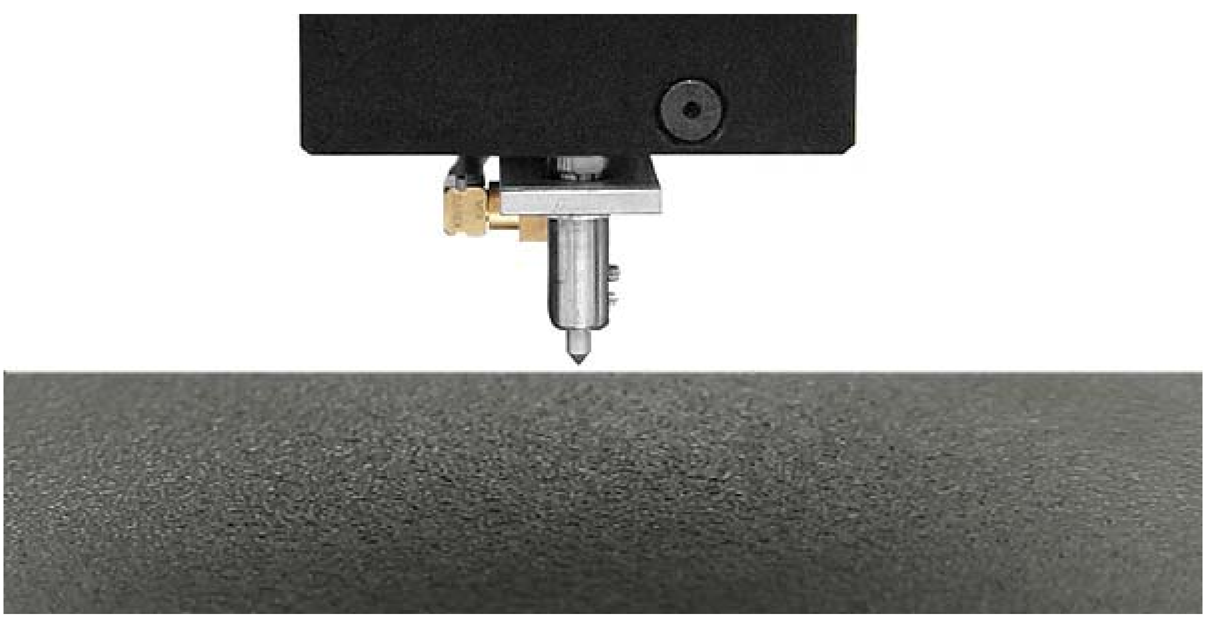
The intention of shot peening is ultimately to alter the mechanical properties of a given surface. By hitting the surface with controlled shot the surface will deform plastically. Two of the more common techniques include cast sheet shot and cut wire shot. Cut wire shot is created by cutting drawn steel wire to lengths approximately the same size as the width of the wire. The resulting wire is then rounded to remove the sharp edges. Cast steel shot is created by atomizing molten steel, then heat treating and sieving the resulting material. In both cases, the surface of the material is hit with a controlled energy of shot to create the desired effect. Understanding the mechanical properties of the surface reactions created by these techniques is becoming increasingly important in various applications including medical, aerospace and automotive industries. Proper Instrumentation will play a vital factor in achieving reliable and intended results.

IMPORTANCE OF NANOINDENTATION FOR PEENED SURFACES

Traditionally, the Rockwell hardness test has been used to evaluate peened surfaces. Unfortunately, because of the size of the indenter used and the high load applied, the data is very unreliable and has little to do with the actual surface affected by the peening process. This is because Rockwell indents easily exceed 100's of microns in depth while the peened depth is only in the range 25microns or so. Using Nanoindentation, which provides precise depth versus load data, hardness and elastic modulus at depths well under 4 to 5 microns can be directly measured. This shallow test is required to study this effect of shot peened without the influence of untreated zones.

MEASUREMENT OBJECTIVE

In this application, the Nanovea Mechanical Tester, in Nanoindentation mode, is used to study the mechanical properties of two separately peened surfaces versus an untreated surface for comparative review. The sample was designed as a single piece of steel with three specific zones: two peened treated areas with one done under cut wire technique and the other done under cast steel technique. The third zone was kept untreated for reference. For Nanoindentation on rough surfaces, it is necessary to find and position the indenter directly on a relatively smooth area. In our case here, smooth areas could be found on the crests of the shot bump created.



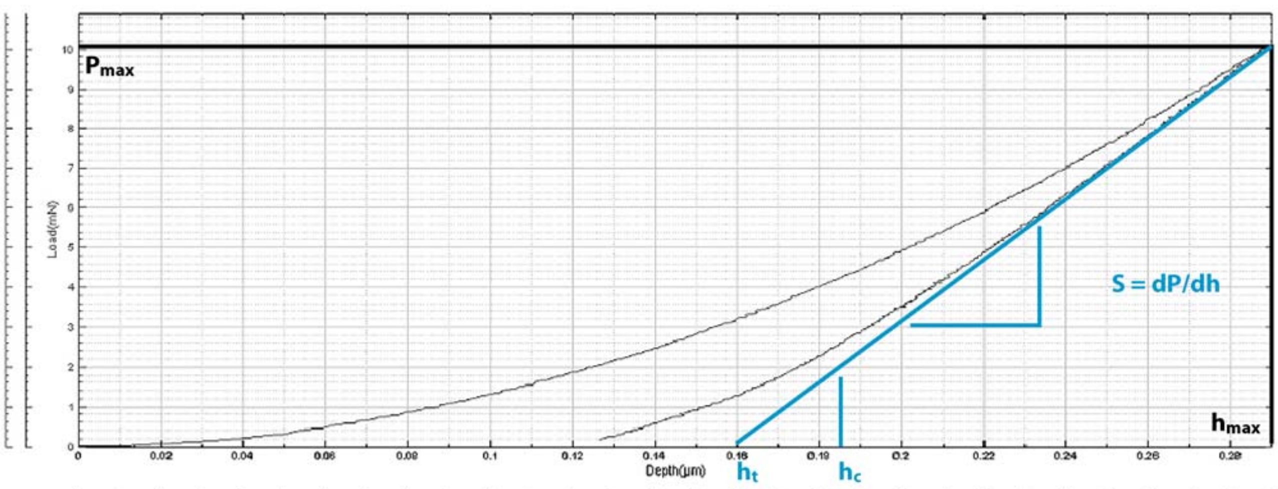
MEASUREMENT PRINCIPAL

Nanoindentation is based on the standards for instrumented indentation, ASTM E2546 and ISO 14577. It uses an already established method where an indenter tip with a known geometry is driven into a specific site of the material to be tested, by applying an increasing normal load. When reaching a pre-set maximum value, the normal load is reduced until complete relaxation occurs. The load is applied by a piezo actuator and the load is measured in a controlled loop with a high sensitivity load cell. During the experiment the position of the indenter relative to the sample surface is precisely monitored with high precision capacitive sensor.The resulting load/displacement curves provide data specific to the mechanical nature of the material under examination. Established models are used to calculate quantitative hardness and modulus values for such data. Nanoindentation is especially suited to load and penetration depth measurements at nanometer scales and has the following specifications:

Maximum displacement (Dual Range)	: 50 μm or 250μm
Depth Resolution (Theoretical)	: 0.003 nm
Depth Resolution (Noise Level)	: 0.05 nm
Maximum force	: 400 mN
Load Resolution (Theoretical)	: 0.03 μN
Load Resolution (Noise Floor)	: 1.5 μN

Analysis of Indentation Curve

Following the ASTM E2546 (ISO 14577), hardness and elastic modulus are determined through load/displacement curve as for the example below.



Hardness

The hardness is determined from the maximum load, P_{max}, divided by the projected contact area, A_c:

$$H = \frac{P_{max}}{A_c}$$

Young's Modulus

The reduced modulus, E_r, is given by:

$$E_r = \frac{\sqrt{\pi}}{2}\frac{S}{\sqrt{A_c}}$$

Which can be calculated having derived S and A_C from the indentation curve using the area function, A_C being the projected contact area. The Young's modulus, E, can then be obtained from:

$$\frac{1}{E_r} = \frac{1-\nu^2}{E} + \frac{1-\nu_i^2}{E_i}$$

Where E_i and ν_i are the Young's modulus and Poisson coefficient of the indenter and ν the Poisson coefficient of the tested sample.

How are these calculated?

A power-law fit through the upper 1/3 to1/2 of the unloading data intersects the depth axis at h_t. The stiffness, S, is given by the slope of this line. The contact depth, h_c, is then calculated as:

$$h_c = h_{max} - {3P_{max}}/{4S}$$

The contact Area Ac is calculated by evaluating the indenter area function. This function will depend on the diamond geometry and at low loads by an area correction.

For a perfect Berkovich and Vickers indenters, the area function is $A_c=24.5h_c^2$ For Cube Corner indenter, the area function is $A_c=2.60h_c^2$ For Spherical indenter, the area function is $A_c=2\pi Rh_c$ where R is the radius of the indenter. The elastic components, as previously mentioned, can be modeled as springs of elastic constant E, given the formula: $\sigma = E\varepsilon$ where σ is the stress, E is the elastic modulus of the material, and ε is the strain that occurs under the given stress, similar to Hooke's Law. The viscous components can be modeled as dashpots such that the stress-strain rate

relationship can be given as, $\sigma = \eta\frac{d\varepsilon}{dt}$

where σ is the stress, η is the viscosity of the material, and dε/dt is the time derivative of strain.

Since the analysis is very dependent on the model that is chosen. Nanovea provides the tool to gather the data of displacement versus depth during the creep time. The maximum creep displacement versus the maximum depth of indent and the average speed of creep in nm/s is given by the software. Creep may be best studied when loading is quicker. Spherical tip might be a better choice.

Other tests possible includes the following:

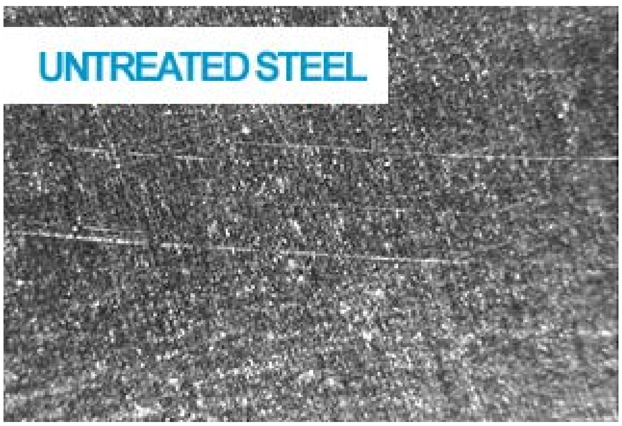
Stress-Strain, Yield Strength Creep, Compression strength and Fatigue testing and many others.

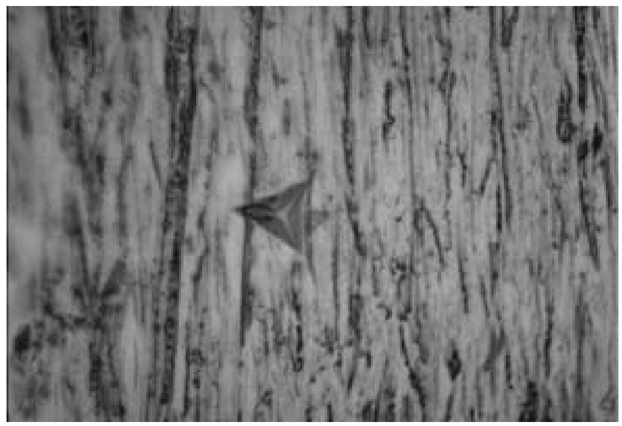
TEST CONDITIONS & PROCEDURES

The following indentation parameters were used:

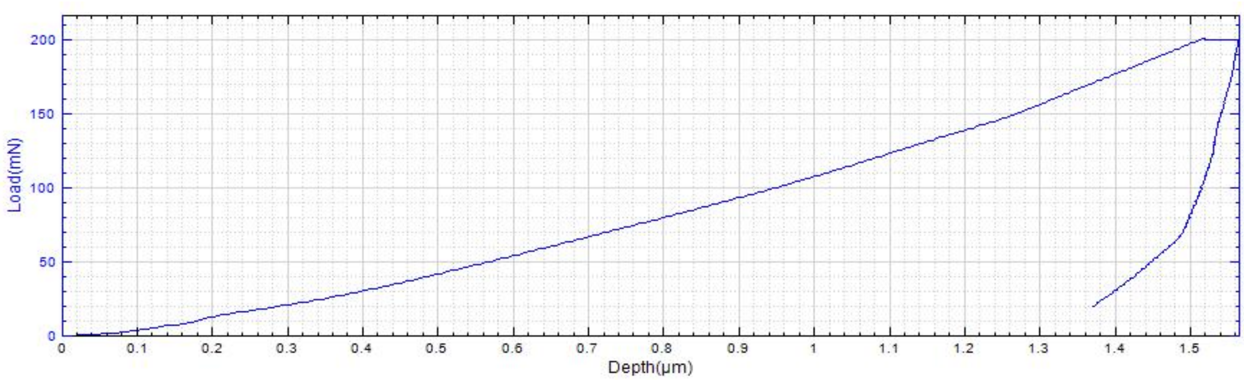
Applied Force (mN)	200
Loading rate (mN/min)	400
Unloading rate (mN/min)	400
Indenter type	Berkovich

RESULTS

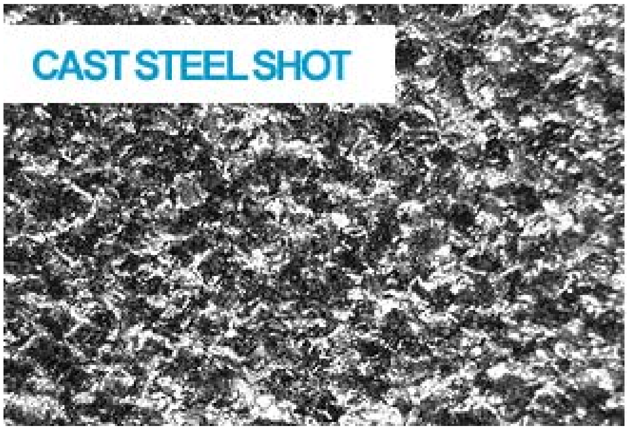




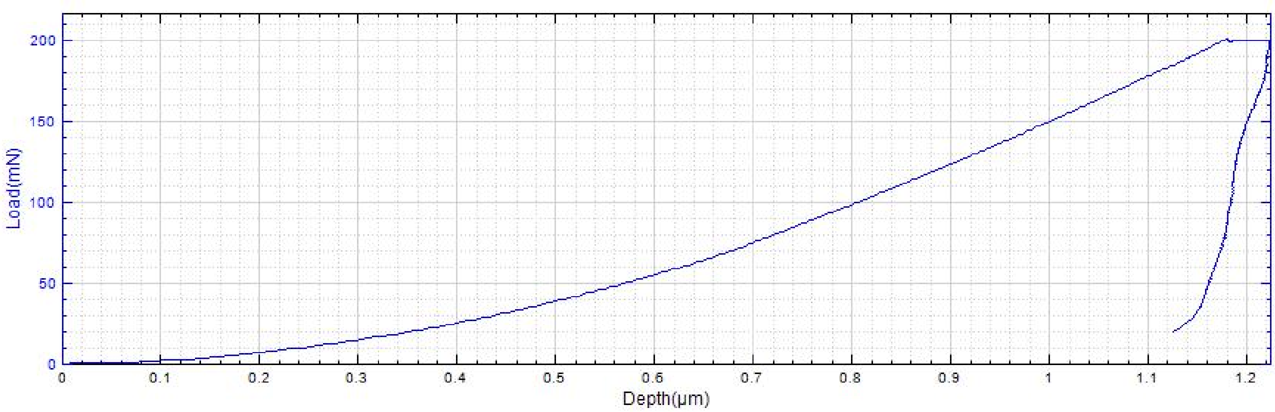
	Hardness	Hardness	Modulus	Depth
	Vickers	Gpa	Gpa	nm
test 1	288	3.05	317	1697
test 2	298	3.16	213	1695
test 3	364	3.85	241	1542
test 4	328	3.47	268	1610
test 5	329	3.47	308	1601
test 6	354	3.75	282	1550
average	**327**	**3.46**	**272**	**1616**
stdev	**30**	**0.31**	**40**	**68**



RESULTS

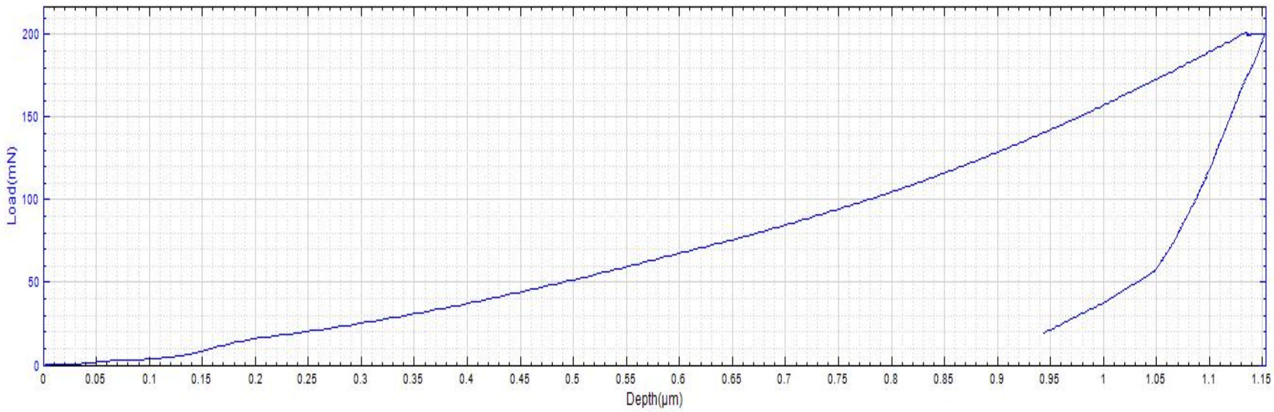


S-170	Hardness	Hardness	Modulus	Depth
	Vickers	Gpa	Gpa	nm
test 1	554	5.86	287	1272
test 2	776	8.21	287	1106
test 3	724	7.66	340	1124
test 4	630	6.67	283	1205
average	**671**	**7.1**	**299**	**1177**
stdev	**85**	**0.90**	**24**	**66**



RESULTS

SCW20	Hardness	Hardness	Modulus	Depth
	Vickers	Gpa	Gpa	nm
test 1	616	6.52	694	1171
test 2	577	6.11	511	1218
test 3	704	7.45	731	1101
test 4	645	6.83	498	1159
test 5	693	7.34	332	1147
average	**647**	**6.85**	**553**	**1159**
stdev	**53**	**0.56**	**162**	**42**



DISCUSSION & CONCLUSION

Both shot peened techniques revealed close to double the hardness measured on the untreated surface. We have measured more variation on the cast steel shot versus cut wire which is expected because of the non uniformity of beads size compared to the uniformity of the cut wire technique. Because both areas were created with the same intensity, it was expected as measured that the average hardness would be similar. The elastic modulus of cast steel zone was slightly higher than what was found on the untreated surface. However, the elastic modulus measured in the cut wire zone was almost double that of the two other zones. This increased plastic reaction may be caused by a reaction similar to forging provided by the cut wire technique. Cast materials will give isotropic properties which could explain the closeness to the untreated area. A forging process will create a surface with properties that differs in various directions.

In conclusion, we have shown that the Nanovea Mechanical Tester, in Nanoindentation Mode, is extremely reliably tool to measure and investigate shot peened surfaces. Other test such as yield strength using a five micron flat tip (patent pending) could provide additional information on the surface using Nanoindentation, among many other measurements. Roughness is a concern with this type of surface and the low load used. However, with good microscopy and precise location it is possible to find smooth area to perform these low load tests.