



# Static Indentation Load Capacity of the Superelastic 60NiTi for Rolling Element Bearings

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## **Abstract**

The nickel-rich, binary nickel-titanium alloys, such as 60NiTi (60Ni-40Ti by wt%), are emerging as viable materials for use in mechanical components like rolling element bearings and gears. 60NiTi is a superelastic material that simultaneously exhibits high hardness and a relatively low elastic modulus (~100 GPa). These properties result in the potential to endure extremely high indentation loads such as those encountered in bearings, gears and other mechanical components. In such applications, quantifying the load that results in permanent deformation that can affect component performance and life is important. In this paper, the static load capacity is measured by conducting indentation experiments in which 12.7 mm diameter balls made from the ceramic  $\text{Si}_3\text{N}_4$  are pressed into highly polished, hardened 60NiTi flat plates. Hertz stress calculations are used to estimate contact stress. The results show that the 60NiTi surface can withstand an approximately 3400 kN load before significant denting (>0.6  $\mu\text{m}$  deep) occurs. This load capacity is approximately twice that of high performance bearing steels suggesting that the potential exists to make highly resilient bearings and components from such materials.

## **Introduction**

Nickel-rich, binary nickel-titanium alloys, such as 60NiTi or alternatively NiTiNOL 60, are under consideration as candidate materials for use in mechanical components (Ref. 1). 60NiTi (60Ni-40Ti by wt%) exhibits an unusual combination of physical properties that impact the design and performance of mechanical components especially rolling element bearings (Ref. 2). 60NiTi is highly corrosion resistant and because it contains no iron it is immune to the atmospheric rusting behavior experienced by bearing and gear steels, even those deemed “stainless” such as 440C. 60NiTi can be hardened through simple heat treatment to levels comparable with conventional bearing steels (Rockwell C 58-62). Prior to hardening, it can be machined using commonplace manufacturing techniques and carbide tools. Grinding, polishing and lapping after heat treatment can yield precision final dimensions and surface finish. 60NiTi is electrically conductive, non-magnetic and has a thermal expansion coefficient closely matched to superalloys and other common structural materials. Though not lightweight, 60NiTi has a density 15 percent lower than steels. Table I shows representative properties for 60NiTi alongside the better-known shape memory alloy 55NiTi (55Ni-45Ti by wt%) and selected conventional bearing materials.

One property that differs substantially from that of bearing steel is elastic modulus. 60NiTi has a modulus similar to titanium and aluminum and is approximately one-half that of steels and superalloys. The reduced elastic modulus for 60NiTi, compared to steel, affects highly loaded, concentrated contacts that occur inside mechanical components. Specific examples include tooth contacts in meshing gears and ball and roller-raceway contacts in rolling element bearings. Figure 1 depicts such contacts schematically.

TABLE I.—NOMINAL PROPERTIES FOR CONVENTIONAL BEARING ALLOYS AND 55NiTi AND 60NiTi

Property	60NiTi	55NiTi	440C	Si <sub>3</sub> N <sub>4</sub>	M-50
Density	6.7 g/cc	6.5 g/cc	7.7 g/cc	3.2 g/cc	8.0 g/cc
Hardness	56 to 62 HRC	35 to 40 HRC	58 to 62 HRC	1300 to 1500 Hv	60 to 65 HRC
Thermal conductivity W/m-°K	18	19	24	33	~36
Thermal expansion	$\sim 12.4 \times 10^{-6}/^{\circ}\text{C}$	$\sim 10 \times 10^{-6}/^{\circ}\text{C}$	$10 \times 10^{-6}/^{\circ}\text{C}$	$2.6 \times 10^{-6}$	$\sim 11 \times 10^{-6}/^{\circ}\text{C}$
Magnetic	Non	Non	Magnetic	Non	Magnetic
Corrosion resistance	Excellent	Excellent	Marginal	Excellent	Poor
Tensile/Flexural strength	$\sim 1000$ MPa	$\sim 900$ MPa	1900 MPa	600 to 1200 MPa (Bend strength)	2500 MPa
Young's modulus	$\sim 95$ GPa	$\sim 100$ GPa	200 GPa	310 GPa	210 GPa
Poisson's ratio	$\sim 0.34$	$\sim 0.34$	0.3	0.27	0.30
Fracture toughness	TBD	TBD	22 MPa/ $\sqrt{\text{m}}$	5 to 7 MPa/ $\sqrt{\text{m}}$	20 to 23 MPa/ $\sqrt{\text{m}}$
Maximum use temp	$\sim 500$ °C	$\sim 300$ °C	$\sim 400$ °C	$\sim 1100$ °C	$\sim 400$ °C
Electrical resistivity	$\sim 80 \times 10^{-6}$ Ω-cm	$\sim 80 \times 10^{-6}$ Ω-cm	$\sim 36 \times 10^{-6}$ Ω-cm	Insulator	$\sim 60 \times 10^{-6}$ Ω-cm

TBD means "to be determined"

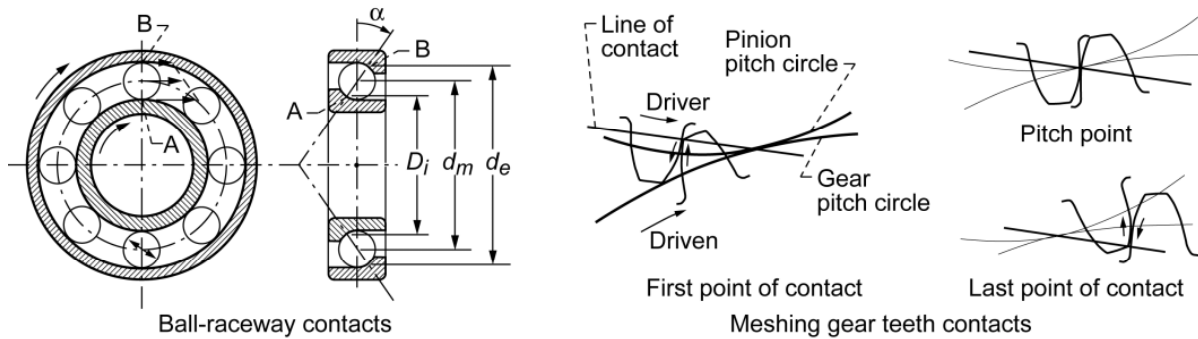


Figure 1.—Hertz concentrated contacts in bearings and gears.

In these instances, a reduced elastic modulus (lower material stiffness) results in more elastic deformation increasing the contact area and reducing the stress levels. This may enhance the static load capacity of such mechanical systems. In addition, a high elastic deformation range is commonly observed for superelastics and this could significantly enhance indentation load capacity. However, the low modulus and resulting increased contact area can have negative effects on internal bearing geometry, rolling friction and wear. Though the detailed characterization of the modulus over a wide range of loads and deformations is beyond the scope of the present investigation, it does remain an important topic.

60NiTi is in the family of intermetallic materials known for their superelastic behavior. A key characteristic of these materials is that they exhibit extraordinarily high amounts of recoverable elastic deformation when heavily loaded. Whereas typical hardened bearing steels can withstand less than 1 percent elastic strain before permanent damage occurs, superelastic materials can frequently withstand over 5 percent strain without experiencing significant plastic damage. Superelastics achieve this characteristic because under high stress they undergo a fully reversible phase transformation that is accompanied by a volume change. Though the exact mechanism continues to be investigated, this phenomenon is well recognized and has been reported in the literature (Refs. 3 and 4).

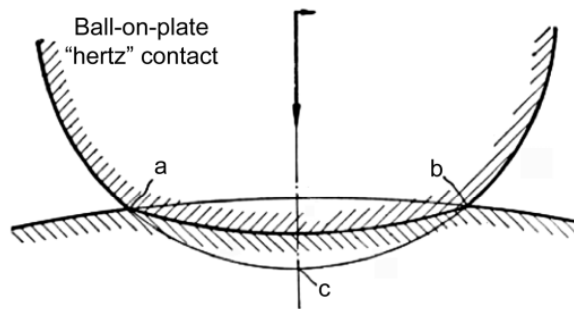


Figure 2.—Single ball-on-race Hertz concentrated contacts in a bearing (exaggerated deformation).

Static load capacity is indeed important for a variety of mechanical component applications, most notably bearings for use in space that must endure high vibration and shock loads encountered during rocket launch (Ref. 5). In such applications, the bearings are stationary during launch and the bearing balls and gear teeth experience damaging dynamic inertial forces. To assure that precision systems function properly once in orbit, many designers add structural load margins to bearings and gears or add vibration isolation devices. These approaches add weight and complexity to space systems. The use of more resilient materials for bearings and gears may alleviate this challenge.

Figure 2 depicts a generic ball-on-race hertz contact with an exaggerated deformation  $\overline{ab}$  to elucidate this effect. When loads are transmitted through a bearing, the materials must resist permanent deformation. If the loads are applied while the bearing is not rotating (e.g., as would be the case for a space instrument during launch), the contact mimics a ball on plate. From a rolling element bearing perspective, any damage that reduces fatigue life or causes unacceptable bearing operation (torque noise) is to be avoided. An obvious type of damage resulting from an overload condition is denting of bearing raceways.

Since torque noise and fatigue-dent depth relationships for 60NiTi do not yet exist, steel-bearing heritage can be used to determine a reasonable dent depth threshold as a starting point. As bearing performance and standard fatigue property data for 60NiTi becomes available this topic like the measurement of the modulus mentioned earlier may also need to be revisited.

For steel bearings, an early dent depth criterion was that surface dents caused by ball-race static loading that are shallower than one-ten-thousandth of the ball diameter can be ignored (Ref. 5). For a 12.7 mm (0.5 in.) diameter ball this translates to a  $1.3\ \mu\text{m}$  (50  $\mu\text{in.}$ ) deep dent. Such dents can be detected on a ground surface using a stylus profilometer and can easily be observed when viewing a highly polished surface, like a bearing raceway, with the unaided eye. This criterion was used to determine the threshold static load capacity for 60NiTi reported on previously (Ref. 1) and it was found to be much ( $\sim 2$  to  $5\times$ ) higher than traditional bearing steels. The exact nature and magnitude of the resiliency benefit, however, may be unclear.

These preliminary results were obtained on ground 60NiTi surfaces with roughness that made the quantification of dents shallower than about  $1.3\ \mu\text{m}$  (50  $\mu\text{in.}$ ) difficult. A literature review of the effects of shallow dents on bearing fatigue and quiet running (torque noise) suggests that dents below the  $1.3\ \mu\text{m}$  (50  $\mu\text{in.}$ ) threshold depth cannot be ignored (Refs. 5 to 7). Permanent dents that are smaller are more difficult to detect but can affect bearing operation under some circumstances.

Using full-scale bearing tests Leveille and Murphy put forth more stringent requirements when applying precision bearings in instrument applications (Ref. 5). In this paper published in 1973, they considered smooth operation and torque ripple rather than fatigue life as their damage criterion. Their work consisted of intentionally loading static instrument bearings until they were able to detect unacceptable torque variations (ripple). They then disassembled the bearings and measured the raceway damage (dents) imparted by the balls using a stylus surface profilometer. Their work showed that even  $0.75\ \mu\text{m}$  (30  $\mu\text{in.}$ ) deep dents, too small to see by the naked eye, degrade the smooth operation of a ball

bearing. Based upon this work, they proposed a quiet running damage criterion that dents greater than 0.00005 of the ball diameter should be avoided. For a 12.7 mm (0.5 in.) diameter ball this translates to a dent depth limit of about 0.6  $\mu\text{m}$  (25  $\mu\text{in.}$ ).

More recently, Park et al., extended Leveille's earlier work by combining full bearing fatigue life tests with ball-on-highly polished plate indentation measurements for conventional bearing steels and emerging high carbide tool steels (Refs. 6 and 7). In that work, a method is outlined to conveniently conduct indentation tests using a load frame followed by dent characterization using stylus profilometry. The results showed that indentation resistance (static load capacity) was highly correlated with hardness and that a more conservative threshold dent depth range of 0.00003 to 0.00005 is recommended. For the hardest tool steels, with Rockwell C values in the range of HRC 65 to 67, loaded to the damage threshold, mean static contact pressures of 585 ksi were observed. This was significantly higher than the stress capability of steels with hardness in the range of HRC 58 to 60. Since the hardness of 60NiTi is in the lower range of conventional steels the extraordinarily high load capacity previously observed is surprising. However, when one considers that 60NiTi has a relatively low elastic modulus ( $\sim 1/2$  that of steel) and exhibits high levels of elasticity the enhanced load capacity is to be expected.

Given that the near term applications for 60NiTi include space instrument bearings, it is imperative that the "quiet running" indentation load capacity using the more stringent (dent depth  $\sim 0.00005 \times$  ball diameter) criterion be ascertained. In the current paper, the Brinell threshold load capacity experiments previously conducted for ground hot-rolled 60NiTi plates are repeated using specially designed 60NiTi indent specimens prepared from the most advanced pre-alloyed powder metallurgy process (Ref. 1). These specimens present a flat, highly polished surface to be indented with ceramic ( $\text{Si}_3\text{N}_4$ ) bearing quality balls in an effort to mimic the contacts inside a ball bearing. It is expected that these more refined measurements will help elucidate the contact behavior of hard superelastic candidate bearing materials like 60NiTi.

## Materials and Procedures

The flat plate indentation specimens are cut from ingots of 60NiTi made via hot isostatic pressing (HIP) of high purity pre-alloyed powders. The powder metallurgy process yields a uniform, fine-grained microstructure that can be readily machined prior to hardening and is largely free of flaws, inclusions and voids that can cause spontaneous fracture during quenching (Ref. 8). Figure 3 shows cross sections of the test material before and after a typical heat treatment that consists of a 1000 °C vacuum solution treatment followed by rapid water quench. This process results in typical hardness values of HRC 60 to 62.

The careful polishing and acid etching of the surfaces revealed the unexpected presence of large ( $\sim 150 \mu\text{m}$ ) unconsolidated 60NiTi particles within the overall matrix. The exact cause for the incomplete particle consolidation during the HIP phase of the material production remains under investigation. Precursor experiments using both cast and powder metallurgy materials without such flaws have shown that these large-scale features have no measurable effect on the indentation hardness tests conducted as part of the present study.

During exploratory indent experiments on large polished flat plates it was discovered that locating very small and shallow indents for measurement is a metrology challenge. The shallow dents sought are invisible to the naked eye and difficult to distinguish from the original adjacent surfaces even when they are highly polished and reflective. The use of surface marking aids, such as an ink pen, is problematic because the marks add surface features (raised areas) that can mask the dents. For higher indentation loads and larger resulting dents, there is also a possibility that nearby surfaces adjacent to the dents can be deformed further confounding the measurements. To overcome these challenges, a unique plate geometry was developed that consists of a large, thick plate of 60NiTi with multiple separate, small-diameter raised regions (lands) that each serve as a site for a single indent experiment. This specimen configuration also made metallographic polishing of the test surfaces convenient. Figure 4 shows a photograph of the indent specimens.



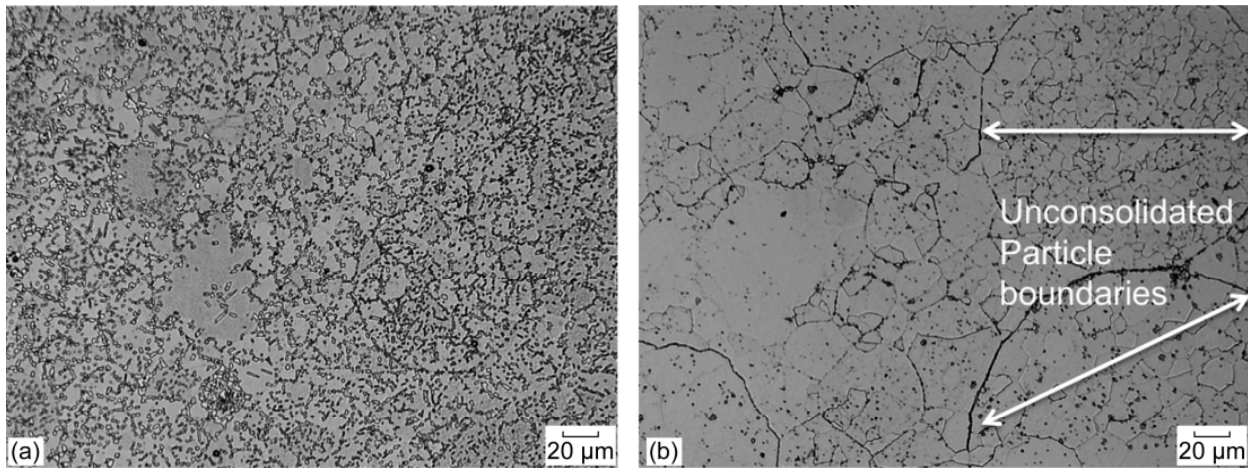


Figure 3.—Optical micrographs of 60NiTi made via the NASA-Abbott powder metallurgy process (a) before and (b) after heat treatment process. Cross sections have been polished and acid etched to accentuate microstructure.

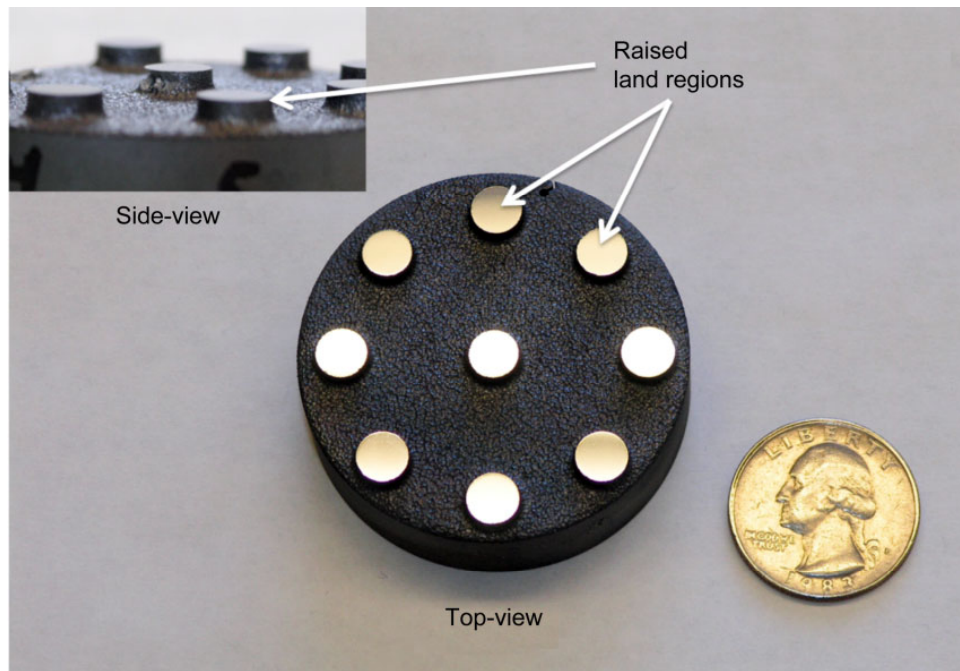


Figure 4.—60NiTi indentation specimen made to facilitate metallographic polishing, indent location and to prevent indent events from confounding adjacent dent experiments.

The specimen size and shape closely matches standard metallographic mounts making polishing simple and straightforward. Each specimen has nine circular (6 mm diameter) indent regions that stand proud of the specimen surface approximately 3 mm. One indent is positioned in the center of each of these polished raised lands. The overall specimen thickness (10 mm) and diameter (25 mm) conveniently fit inside the inner race of ball bearing blanks cut from larger ingots as part of a bearing development project. Essentially, the indent specimens are made from scrap material and thus very closely mimic bearing race material. By indenting the center of the polished raised lands the dent location is easier to find during later profilometry. Further, the use of raised lands ensures that dent experiments on one land will not affect the material of an adjacent land.

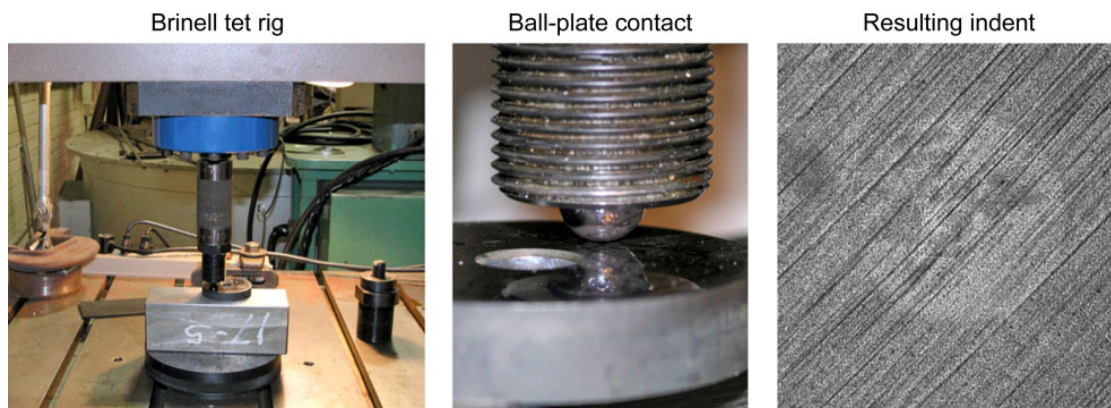


Figure 5.—Brinell test configuration used for indentation experiments to measure static load capacity.

$\text{Si}_3\text{N}_4$  balls, 12.7 mm in diameter, are used to dent the 60NiTi surfaces in these experiments. The general configuration, shown in Figure 5, is essentially a Brinell test and it closely mimics the approach used by Park and his colleagues to establish the static load capacity of advanced, high carbide content steels (Refs. 6 and 7).

In our tests, the ball is loaded against the flat plate surface using a computer controlled load frame. The indent ball is held in a hemispherical recess machined into a standard steel push rod. A small volume of silicone vacuum grease is applied to the surface of the recess prior to inserting the ball to help secure the ball against gravity and to ease subsequent ball removal.

To conduct a test, the selected raised land of a plate specimen is positioned directly beneath the ball and aligned by eye such that the indent occurs at or near the center of the raised land. The push rod-ball assembly is then manually lowered by pressing the “lower head” control button on the load frame controller. When the ball is within 1 mm of the surface the control button is released and the operator then engages an automated computer controlled indent program that slowly lowers the ball until a load cell detects contact. The load is then increased linearly at approximately 100  $\text{kg}_f$  per minute until the desired static load is reached at which time the load is held steady (within ~5 percent) by the control system. After a dwell period (typically 1 min) the push rod-ball assembly is raised to remove the load and the test concludes.

Our test procedure differs slightly from that reported in the literature (Refs. 6 and 7). In that work, the load was applied manually and allowed to rest at the maximum load for relatively long periods (5 min). In our test, the load was ramped in a controlled fashion and no attempt was made to let the test load rest for a set period of time. To determine if this might influence the results, several repeat tests were run in which the load was left to stabilize for extended periods of time (15 min or more) but no differences in resulting indents were observed. Another small difference between our tests and those of Park et al. is indent ball size. Our balls were slightly larger (12.7 mm in diameter vs. 12.5 mm in diameter). This small difference will change the hertz contact stress calculations slightly but is not expected to alter the overall results. Based upon these considerations, it appears that our test protocol and configuration closely matches that reported in the literature.

The goal of these tests is to determine the static load capacity of the 60NiTi. We define this load as that which results in a permanent dent depth that is equal to 0.00005 of the indent ball diameter, the so-called “quiet running” dent. For our case, this translates into a dent depth threshold of  $0.64\text{ }\mu\text{m}$  (25  $\mu\text{in.}$ ). To determine this load capacity, a series of initial indent experiments are conducted starting at a low load of 50  $\text{kg}_f$  and increasing in increments of 50  $\text{kg}_f$  (e.g., 50, 100, 150, 200, 250, 300  $\text{kg}_f$ , etc.) until a clearly visible dent is observed. Once the general static load capacity limit is visually determined and corroborated through subsequent surface profilometry, three or more repeat experiments are conducted slightly (25  $\text{kg}_f$ ) above and below the initial load capacity estimate. In this manner both the general indent depth versus load and the specific static load capacity for 60NiTi can be determined.

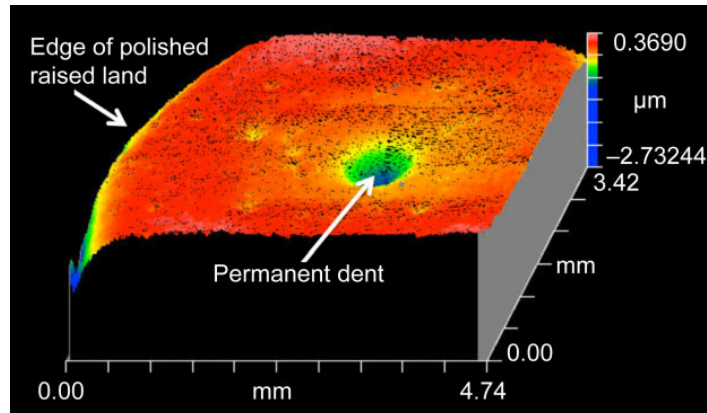


Figure 6.—Representative contour plot of dented 60NiTi surface as measured by optical (non-contact) surface profilometry.

Following the indent experiments, the flat plate specimens are measured using a non-contacting optical profilometer. With this technique, first a fairly broad area (square mm) around the center of each raised land is scanned to develop a low-resolution surface topography image. This area image guides subsequent, higher resolution depth measurements to be made on the dent itself, which may not be exactly centered on the land depending upon the alignment during the test. By stitching multiple measurements together, a contour plot of the dent and the surrounding undisturbed surface is then made. A typical dent measurement plot is shown in Figure 6.

## Results and Discussions

The hardened and polished raised land 60 NiTi specimen surfaces were each loaded a single time with a 12.7 mm diameter Si<sub>3</sub>N<sub>4</sub> indenter ball. After the indentation experiment, the resulting dents were examined as described in the previous section. The indentation data is summarized in Table II using a nominal constant value of 100 GPa for the modulus of 60 NiTi.

TABLE II.—INDENTATION DEPTH DATA SUMMARY  
 {Si<sub>3</sub>N<sub>4</sub> Ball (12.7 mm diameter) loaded against hardened (HRC 60.5) polished flat 60NiTi surface}  
 Quiet running dent depth limit: 0.6 μm  
 Fatigue life dent depth limit: 1.4 μm

Indent load, kg <sub>f</sub> (lbs)	Mean stress, GPa (ksi)	Peak stress, GPa (ksi)	Contact diameter, mm (in.)	Dent depth, μm (μin.)
50 (110)	1.67 (242)	2.51 (364)	0.61 (0.024)	None detected
100 (220)	2.10 (305)	3.16 (458)	0.76 (0.030)	None detected
150 (331)	2.41 (350)	3.62 (525)	0.86 (0.034)	None detected
200 (440)	2.66 (385)	3.98 (577)	0.97 (0.038)	None detected
250 (551)	2.86 (415)	4.29 (622)	1.07 (0.042)	0.06 (2.5)
300 (661)	3.03 (440)	4.56 (661)	1.12 (0.044)	0.3 (11.8)
350 (771)	3.20 (464)	4.80 (696)	1.17 (0.046)	0.4 (12.1)
375 (826)	3.27 (475)	4.91 (712)	1.19 (0.047)	0.5 (16.1)
400 (881)	3.37 (488)	5.06 (733)	1.22 (0.048)	0.74 (29.1)
450 (992)	3.47 (504)	5.21 (756)	1.27 (0.050)	1.36 (53.5)
500 (1102)	3.60 (522)	5.40 (783)	1.32 (0.052)	1.82 (72)



The dent depth data are plotted in Figure 7 as a function of indent load. Data measurement uncertainty was below  $0.03\text{ }\mu\text{m}$  ( $1.0\text{ }\mu\text{in.}$ ) and scatter amongst repeat tests was higher ( $\sim 0.15\text{ }\mu\text{m}$ ) except for low loads (order  $250\text{ kg}_f$ ) where dent detection was very difficult and scatter increased. At the lowest loads, some dent experiments yielded no measurable dents and others resulted in dents on the order of a few hundredths of a micron. For comparison to bearing operating condition, the quiet running dent criterion is depicted as a horizontal line.

On this graph, the dent behavior of conventional and high performance bearing steels are also plotted using the data from the literature (Refs. 6 and 7). It is clear that from a static load capacity consideration alone, the 60NiTi outperforms conventional bearing steels, even those like REX20 that are much harder, by factors of two or more. If one considers contact stress, however, the results differ dramatically. Figure 8 plots the same dent depth data as a function of mean contact stress.

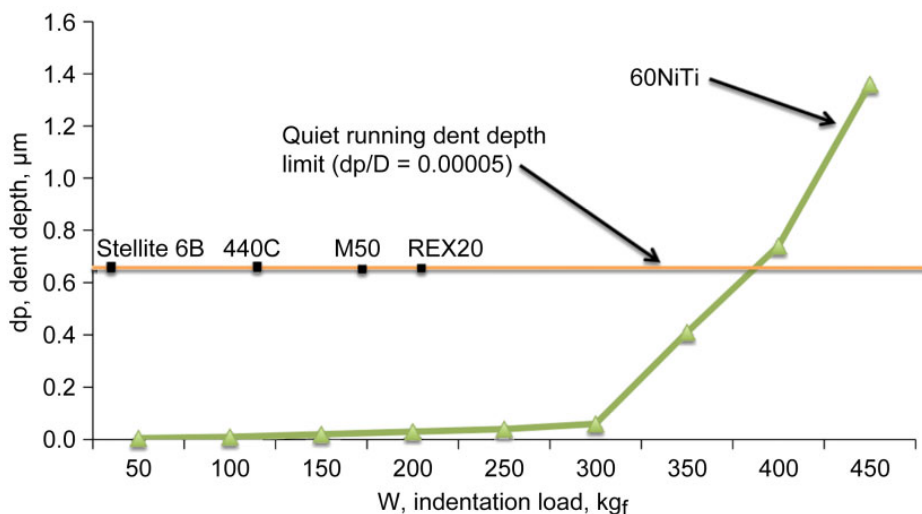


Figure 7.—Indent depths for 60NiTi plate as a function of load when contacted by a 12.7 mm diameter  $\text{Si}_3\text{N}_4$  indenter ball. Data for Stellite 6B, 440C, M50, and REX20 from References 1, 6, and 7.

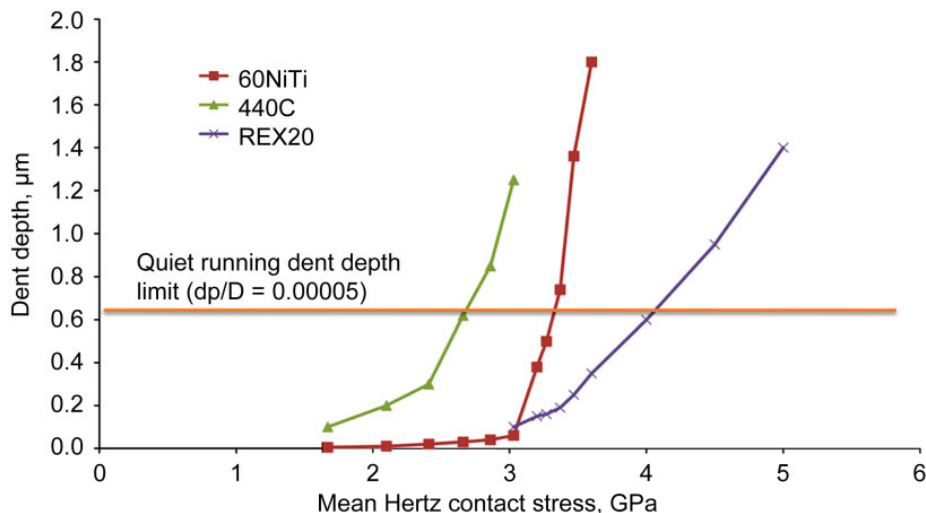


Figure 8.—Indent depths as a function of contact stress for 60NiTi, 440C and REX20 plates loaded with  $\sim 12.7$  mm diameter  $\text{Si}_3\text{N}_4$  indenter ball. The data shown for 440C and REX20 are from Reference 7. Modulus of 60NiTi is considered constant at 100 GPa.

Since the elastic modulus for 60NiTi is relatively low, more elastic deformation occurs during indentation by the stiff  $\text{Si}_3\text{N}_4$  balls. This effectively increases the contact area and reduces peak and mean contact stresses. Thus the 60NiTi superelastic surface is able to withstand higher loads than steels even though its contact stress limit seems to fall between that of 440C and REX20. In the past, with the exception of ceramics like  $\text{Si}_3\text{N}_4$ , the bearing materials considered all have about the same modulus and thus the dent depth plots looked the same regardless of whether they were graphed against stress or load. For 60NiTi this is not the case. Given that bearing load capacity is measured in force, it appears that the use of 60NiTi allows much higher load levels before permanent deformation that affects performance occurs.

The reason or reasons why 60NiTi can withstand higher contact loads before significant permanent deformation occurs is an open subject under ongoing investigation. 60NiTi belongs to the family of superelastic materials that are known to exhibit large recoverable elastic strains especially in compression. Further, when properly heat-treated, 60NiTi attains hardness values (Rockwell C) in the range of HRC 60 to 62, comparable to traditional bearing steels. Figure 9 shows an image of an indent in 60NiTi from the conical diamond Rockwell C indenter.

The dent is deep and narrow and differs considerably from dents left by the much larger and more blunt  $\text{Si}_3\text{N}_4$  ball a typical example of which is shown in Figure 10.

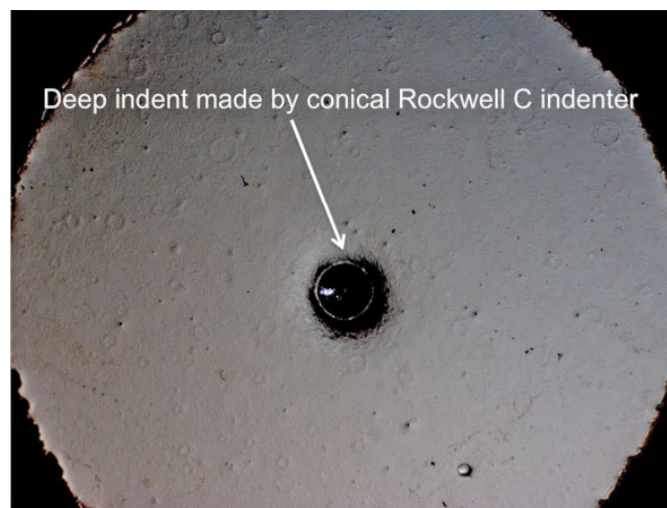


Figure 9.—60NiTi surface after Rockwell C indent made by conical diamond indenter. (Diameter of raised land is 6 mm).

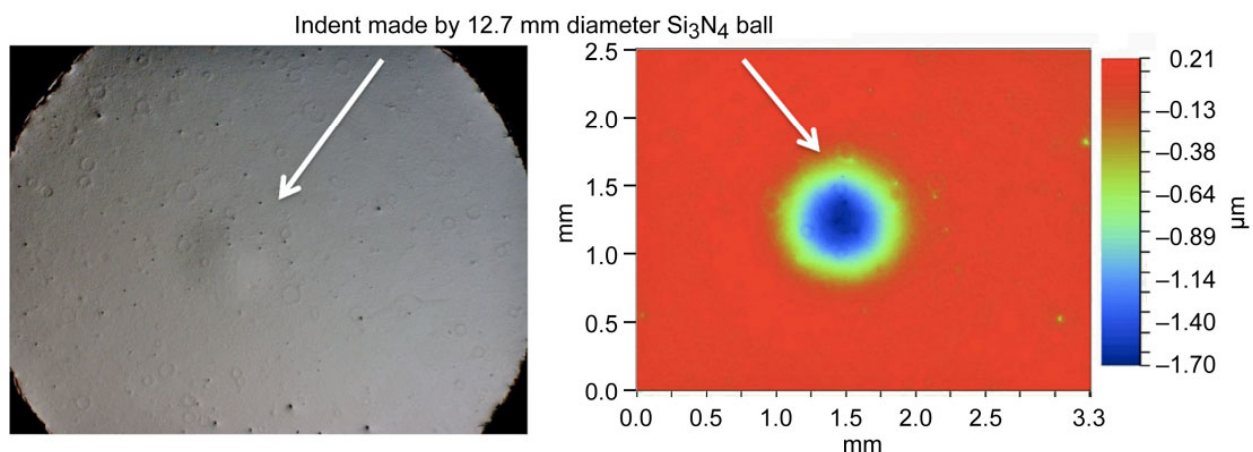


Figure 10.—60NiTi surface after indent made by 12.7 mm diameter  $\text{Si}_3\text{N}_4$  ball loaded to 500 kgf. (Diameter of raised land is 6 mm).

Another way to interpret the images in Figures 9 and 10 is to consider the indenters. For the Rockwell C indent, the damage comes from a sharp conically shaped diamond-tipped indenter forced into the surface under a 150 kg<sub>f</sub> load. The resulting damage is a deep, narrow-sided hole. In an operating bearing, such damage might occur if a hard sharp-featured particle was caught between a ball and raceway. Referring to Figure 10, the damage from the large but smooth indenter, the Si<sub>3</sub>N<sub>4</sub> ball, is much shallower with gentle sloping sides. This gentle but measurable dent would likely have a different effect on bearing behavior than the sharp dent shown in Figure 9. Future investigations involving full scale bearing tests in which the races are seeded with different types of damage will be needed to truly understand these phenomena.

Appropriate selection and application of a bearing material cannot be made using one parameter, such as static indent load capacity, alone. Many other factors must be considered. For instance, the reasoning behind the development of the hard, high carbide containing steel REX20 was to enhance the static load capacity of bearings used in space flight instruments. The use of REX20 does increase static load capacity, while retaining high rolling contact fatigue resistance, but the corrosion resistance is poor, especially compared to stainless steels like 440C. As is often the case, the successful design balances one material attribute against others and matches these capabilities to the requirements of a particular application. It is interesting to note here, that the original inventor of the entire family of NiTi superelastic materials, W.J. Buehler, recognized the potential for 60NiTi corrosion proof bearings but the processing capabilities available during that period hindered his efforts. Now nearly five decades later, having only recently recognized the additional benefits of superelasticity on static load capacity, is the engineering community picking up where Buehler and his colleagues left off (Ref. 8).

## Summary Remarks

The results presented in this paper suggest that the superelastic 60NiTi exhibits a high tolerance to static indentation loads similar to those that might be encountered in space mechanisms during launch. When combined with its intrinsic corrosion resistance and low density it becomes apparent that 60NiTi is a viable candidate for selected bearing applications. The unique combination of high hardness, low elastic modulus and superelastic behavior enable 60NiTi to withstand load levels that result in permanent damage to conventional bearing materials. The exact reason for the high static load capacity of 60NiTi is likely due to its low elastic modulus that leads to increased contact areas and reduced contact stresses. The high elastic range of the superelastic materials, compared to conventional bearing steels, may also be a contributing factor. These phenomena will be studied in future investigations as will the determination of critical rolling contact fatigue behavior.

Ongoing research in the design, manufacture and testing of full-scale bearings made from the superelastic material, 60NiTi are likely to uncover many technical challenges. It is expected that the 60NiTi material and processing technology on hand today will be the basis for alloy development and applications engineering in a wide variety of mechanical systems that can take full advantage of these emerging materials.

Lastly, the importance of doing such detailed characterization of the static load capacity of 60NiTi and the specific methodology used were inspired by the continuing interest and support of Mr. A.R. Leveille who has been a pioneer in this field. The author is deeply indebted to his supportive and guiding interest.

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