What are *Izory*® and *Izory*® HD?

By Tyke Negas, VP of Technology

Historical Perspective

Ronald Garvie and his team of researchers in Australia developed partially (P) stabilized (S) magnesium (Mg) zirconia (Z), Mg-PSZ, in the 1970's and named it "ceramic steel". Materials science researchers worldwide followed quickly with numerous technical publications involving zirconia-based ceramics. Studies stretched into the 1990's. Among the best references is the series of volumes, "Science and Technology of Zirconia". Since then, scientific fervor has slowly diminished seemingly because Mg-PSZ is perceived to be an "old technology". Arguably, that might be so but significant production engineering challenges involving raw materials, binders for powders needed to press large parts, firing cycles to process parts in volume using large kilns, machining, etc. are not trivial. However, the "old technology" impression has some validity because for decades improvements to the properties of the original Mg-PSZ have not been demonstrated conclusively for industrial use.

Structural applications were slow to develop for many reasons. Designers were unaware of Mg-PSZ, did not understand its advantages or were reluctant to use it because ceramics, unlike most metals, fracture easily, i.e. they "break". The term, "ceramic steel", in fact, precisely combats this perception. Also, highly demanding industrial technologies that might benefit from use of Mg-PSZ were not yet mature and, in turn, commercial sources for the ceramic remained limited. Finally, if a ceramic was required, designers always turned to the well established and readily available alumina, Al2O3.

Metallurgists had long established and harnessed the concept of "transformation toughening" and "transformation-assisted strength" for steels wherein the mechanism involves a transition from a higher density, smaller volume crystalline phase to one of lower density and larger volume. This transition, termed "martensitic", can occur under an applied load or stress at/near room temperature. A propagating crack is blunted by volume expansion associated with the transition, energy is absorbed and, thus, resistance to fracture or "fracture toughness" (Kic) is imparted. Garvie et al., realizing that the same mechanism was applicable to Mg-PSZ, developed it using unique ceramic processing. The key to their process was to establish and maintain in the ceramic microstructure a substantial volume fraction of the higher density crystalline phase of zirconia having tetragonal symmetry (T) during cooling of densified ceramic from elevated temperature. The T-phase crystallites were required to be of nanometer size and be constrained in the ceramic matrix. Normal transform to the lower density, larger volume, monoclinic (M) variant on cooling would be avoided but could occur at/near room temperature if a sufficient volume fraction of T-phase in the microstructure was retained at/near a "critical" crystallite size and, thus, capable of transforming. By increasing overall toughness, fissuring from external stresses and internal stress intensifiers such as pores and minor impurity phases also would be minimized.

Today several companies in the USA manufacture Mg-PSZ structural ceramics. *Izory*® and an improved variant, *Izory*®HD, are the versions marketed by Refractron Technologies Corp. (RTC).

Microstructure and Properties

The microstructure of *Izory*® seems abnormal and not especially aesthetic when compared to a customary fine-grained, high strength ceramic. It consists of large domains, 50-80 microns in size, of the cubic (C) variant of zirconia. Intergrown coherently are nano-size lamellae of T-phase normally well resolved by TEM or high-resolution SEM (Fig. 1). Some M-phase develops mostly at domain boundaries and from T-phase unconstrained at ceramic surfaces.

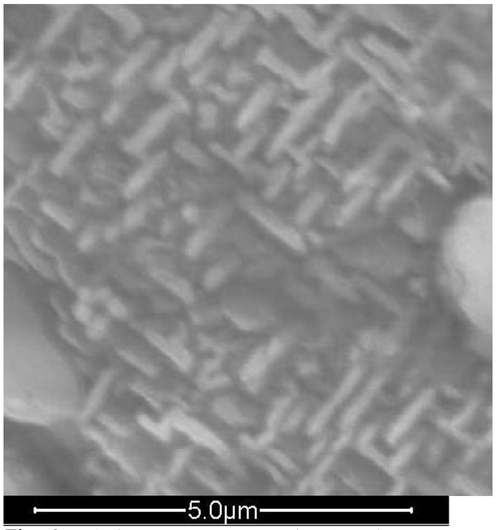

Fig. 1 - *Coherent intergrowth of T-phase lamellae with C-zirconia. The MgO partitions into both solid solution phases*

Typical specs for *Izory*® include density, 5.75/cc; modulus of rupture (MOR, 4-point ASTM), 550 MPa; fracture toughness or resistance to fracture (Kic, ASTM C-1421 Chevron Notch Beam), 10 MPa•m1/2; Vickers hardness (Hv, ASTM C-1327-08), 1050. Wear (wear resistance or behavior) is a complex subject and not an intrinsic property. It is best described for engineering design purposes by what is termed a tribosystem consisting of all influential chemical, mechanical and environmental factors. Fundamental material properties, especially Hv, plus a scientific measure of wear involving volume loss (e.g. ASTM 174, traveling belt containing 30 micron alumina without lubricant) are useful to

MATERIAL	Kic	MOR	Hv	Vol. Loss*, mm³
Izory® (MgPSZ)	11-12	550	1050	0.153
YTZP	6	1400	1600	0.056
Alumina	3-4	400	1800	0.044

Table 1. Key Properties of Important Structural Ceramics

* *Average of numerous tests using different samples from different lots of each ceramic. Different sources for YTZP raw material were used to produce ceramic parts. An Izory® part, measured multiple times, served as an internal standard in every test*

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rank and select materials on a preliminary basis. A comparison of properties, including wear, for *Izory*®, YTZP (yttrium tetragonal zirconia phase or polycrystal) and alumina (Al_2O_3) structural ceramics are shown in Table 1.

It is not surprising that alumina is the best performer given that abrasion is conducted using alumina grit. YTZP samples were obtained from ceramic parts that were given a post-firing hip treatment (high pressure/high temperature). This removes most ceramic defects and is customary for most applications. While possible using a two-step sinter-hip operation, it is not practical to hip *Izory*® because of cost prohibiting specialized equipment required, especially for large parts. Note also that wear scales quite well with Hv as might be expected. Hv also scales well with ease of machining, i.e. *Izory*® being the easiest, alumina the most difficult.

Izory® has lowest Hv but this is deceiving. Lower Hv combined with high Kic allows for fast, aggressive machining without chipping thereby saving labor costs. In addition, lower Hv provides for improved ceramic surface finish by machining/polishing operations. In turn, finer surface finish means less friction between the ceramic and moving components and, hence, longer service life. Less friction also is an often-neglected feature in the tribosystem of *Izory*® that is application specific but difficult to measure. It has been reported that its un-lubricated coefficient of friction, μ, when sliding with hard steel is the lowest among all oxide-based ceramics.

Applications and Properties

Alumina, metal alloys and tungsten carbide in the form of large tubes, rings, rods and spheres traditionally found use as structural products for oil and gas drilling and wire drawing (Fig. 2). These

Fig. 2 - ***Izory*®** *capstan for wire drawing*

applications require resistance to friction/wear to enhance service life, low mass and, of course, low lifetime cost. Oil and gas drilling, including fracking of sands and shales, uses mud pumps that circulate the abrasive fluid of rigs. As seen in the photo in Fig. 3, the structural material serves as

Fig. 3 - ***Izory*®** *metal mud pump assembly*

a tubular sleeve that fits inside of a steel shell where it is subjected to contact with the fluids and an elastomeric or metal piston.

In high-speed wire drawing, the material is used as dies, rings and recessed tubes to progressively thin, route and collect wire. Lubricants are used.

Initially, alumina replaced metals and carbide in these industries because of its combination of lower mass, wear rate and cost. Despite excellent wear and strength, YTZP could not compete because large parts were too costly. For example, the cost of YTZP raw material alone is greater than that of *Izory*® and alumina by at least a factor of three. More recently, *Izory*® has made significant inroads in pumps & valves used in oil and gas, chemical processing, medical, and food processing industries. It is the product of choice in non-ferrous wire manufacturing worldwide. Examples of parts used to manufacture wire (Fig. 4).

Izory® eclipsed alumina primarily because of its higher strength (MOR), higher resistance to fracture (Kic) and its pristine surface finish when polished. The fracture toughness allows for fast, aggressive, chip-free machining and polishing which in turn reduces labor costs and enhances yields. Routine handling of finished parts by the producer and, especially, the user is not an issue since, unlike alumina, *Izory*® is rugged and does not easily chip.

Fig. 4 - *A variety of* ***Izory*®HD** *ceramic parts used in wire manufacturing*

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Why *Izory*®HD?

Izory® has been used successfully in many wire manufacturing applications (Fig. 2), often as “capstans or pull blocks” drawing nonferrous metals that are not highly abrasive. Copper and aluminum dominate that industry segment. However, other metals and metal alloys are drawn and many of these are far more abrasive. Examples include nickel, nickel alloys and stainless steels. Because of its modest dry abrasion resistance and hardness (see above) as compared to other technical ceramics and despite a low coefficient of friction, traditional MgPSZ’s can erode more rapidly and limit long-term use. There was clearly an opportunity to reset the performance expectations for a new cost-effective material in the Wire industry.

Appreciating that improved versions of Mg-PSZ have never been brought to the marketplace (i.e. the perception of an “old technology”), RTC began work focusing on a new generation of *Izory*® with improved hardness and wear resistance. Using additives to *Izory*®, ***Izory*®HD was born.** Its microstructure resembles that of *Izory*® but domain size (coherent intergrowth of C- and T-phases) is reduced to 10 – 20 microns. Here, the bonus is improved rupture strength (MOR) that is in the 650 – 725 MPa range. Density is typically 5.78 – 5.80 g/cc. Fracture toughness remained exceptional and is identical to *Izory*®. Although the hardness of *Izory*®HD is only increased only by ~15% to 1225, this improvement, perhaps, combined with smaller domain size, yields an average wear loss of 0.100 mm3 (compare with values in Table 2). This wear factor approaches that of hipped YTZP!

PROPERTIES

	MgPSZ *Izory*®HD	MgPSZ Typical
FRAC. TOUGHNESS K_{IC} *[MPAm$^{1/2}$] ASTM C-1421*	10	10
LOOP ABRASION *[mm^3] ASTM G174 (d)*	0.100	0.150
MOD. OF RUPTURE 4pt MOR *[MPa] ASTM C-1161*	650	500
HARDNESS VICKERS *[HV1] ASTM C1327-08*	1225	1050

Note: Typical values are not intended to be used as specification. Contact Refractron for application suitability.

Table 2. *Izory*®HD Properties VS traditional Zirconia

The properties of *Izory*®HD looked great but when it was benchmarked in a wire drawing factory using the same machine with nickle 200, monel 400 and 430 stainless steel wires we knew we had a winner. The dramatic results are illustrated in the photos shown in Figure 5. *Izory*® grooved, and adversely impacted drawing and wire quality quickly after drawing 1450 lbs of nickel 200, 3700 lbs of 430 ss and 490 lbs of monel 400. *Izory*®HD was unphased. The surfaces on the *Izory*®HD cone were still pristine!

Those initial results in 2016 encouraged us to start transitioning wire manufacturers to *Izory*®HD . It has now replaced traditional MgPSZ in numerous applications in wire factories around the world and has become the standard for resilient materials that preserve wire quality and extend maintenance cycles. The enhanced properties also allowed *Izory*®HD to flourish in critical pump and valve applications processing food, drilling for oil & gas, metering chemicals, pumping blood, and making batteries (Fig. 6). Contact Refractron to see if *Izory*®HD cn drive product quality, lower total costs, and extend the life of mating components in your critical equipment ■

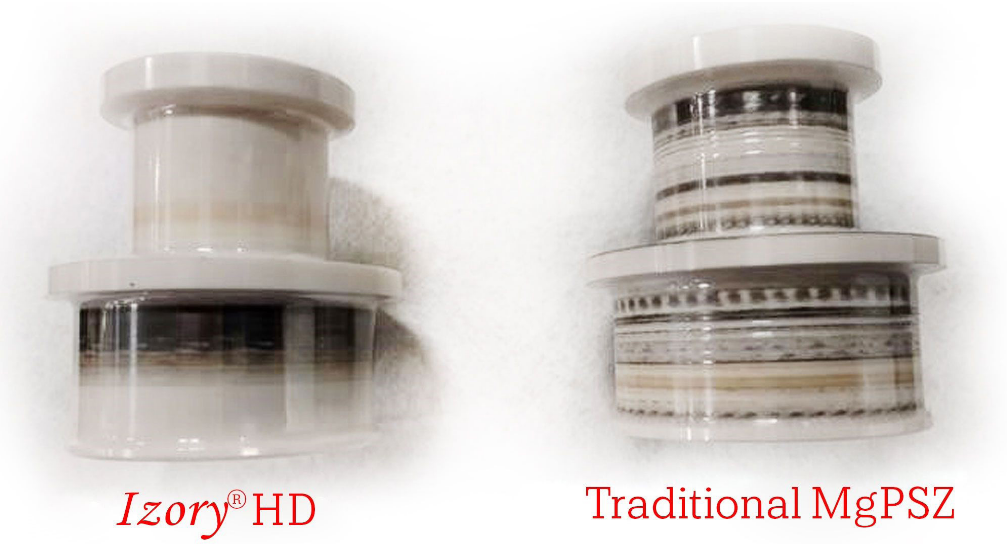
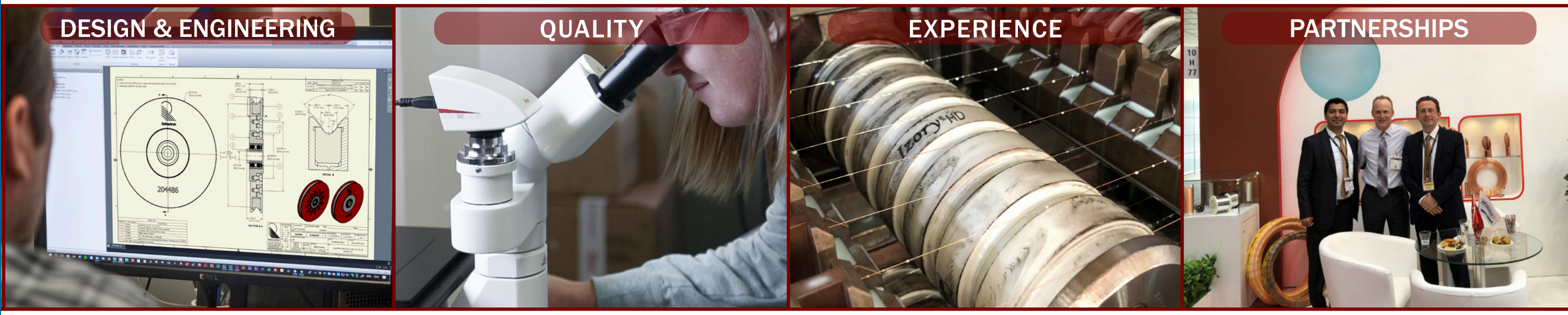


Fig. 5 - *Appearance of **Izory® HD** and **Izory®** after drawing abrasive wires in 2016*

Fig. 6 - ***Izory*®HD** *pump & valve components*



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