Zirconia crucibles: Enabling reliable melting of platinum group metals

Zirconia crucibles in various sizes and compositions, designed for diverse alloy systems and operating temperatures up to 2,300°C.

By Ronny Simon, Jake Mochoskay, and Tobias Schmidt

Crucibles are a key piece of equipment in the world of high-temperature processing, serving as containers for molten materials while they are refined and cast.

Ceramics are the main material used for creating crucibles, but the specific type of ceramic used depends on the material being melted. In the case of platinum group metals (PGMs) and alloys, their high melting points (Table 1) significantly limit the choice of ceramics that can be used for melting compartments.

Zirconia crucibles offer several advantages for processing PGMs. Thanks to developments by companies such as zirconium oxide specialist Zircoa (Solon, Ohio), a range of zirconia products exists to accommodate various alloy types, operating parameters, and target benefits.

PGM applications and processing needs

Pure metals or alloys of platinum, palladium, or rhodium are known to be used in the jewelry industry. However, the much more widely—albeit hidden—uses of these metals involve various industrial processes and aggregates:

- Catalysts for petroleum refining, chemical production, and automotive catalytic converters.
- Melting tanks and stirrers in glass fabrication or bushings for glass fiber production.
- Electrical and electronic components such as thermocouples, contacts, or electrodes, or in conductive and resistive pastes deposited on ceramic substrates in advanced semiconductors.

Because PGMs are rare, expensive, and chemically stable, recycling is both an economically and environmentally important part of the PGM supply chain. First, PGM scrap is collected from the applications mentioned above, and then it is subjected to various crushing, screening, and mechanical pretreatment processes before being melted down. Various methods can be used for melting the scrap, but zirconia crucibles as a melt compartment in an induction furnace are a common option. The precious metals are collected in a metal phase while impurities such as oxides and unwanted metals are captured in the slag. Fluxes with lower melting points support the separation.

For PGMs, the highest purity of the products is mandatory, so the recycling process calls for stringent operating parameters. These requirements make the process chemically and mechanically demanding for the crucible, especially due to the presence of glassy or siliceous slags. Solutions such as zirconia crucibles with superior thermal, chemical, and mechanical stability are thus needed for the process.

Table 1. Platinum group metals and alloys and their melting points.

PGMs and alloys	Melting point (°C and °F)	
Platinum (Pt)	1,768°C	3,215°F
Palladium (Pd)	1,555°C	2,831°F
Rhodium (Rh)	1,964°C	3,567°F
Ruthenium (Ru)	2,334°C	4,233°F
Iridium (Ir)	2,445°C	4,435°F
Osmium (Os)	3,033°C	5,491°F
PtRh10	~1,850°C	~3,360°F
PtRh20	~1,890°C	~3,430°F
PtRh30	~1,930°C	~3,510°F
PtIr10	~1,800°C	~3,270°F
PtRu10	~1,800°C	~3,270°F

Source: Zircoa

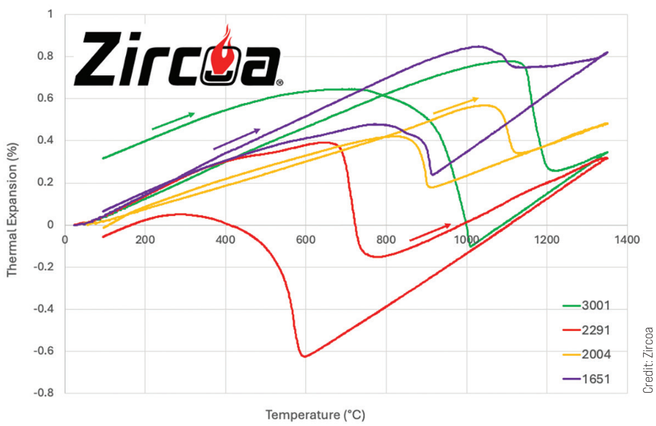

Figure 1. Thermal expansion of Zircoa's crucible compositions upon heating and cooling.

Benefits of zirconia crucibles for PGM processing

Zirconia crucibles offer several advantages for PGM processing compared to other ceramics such as alumina, silica, magnesia, or silicon carbide:

- Reliable performance at extreme temperatures up to and above 2,100°C.
- Excellent chemical stability, meaning no reaction with the melt.
- Exceptional thermal shock resistance, which enables consistent performance throughout extended heating and cooling cycles.
- Highly smooth contact surfaces, minimizing contamination of melt.
- Sustainability benefits due to its multi-use capability (reuse frequency determined by the application).

While other ceramics can offer some of these benefits, zirconia crucibles combine the necessary temperature resistance, mechanical properties, surface quality, and chemical inertness in an ideal way.

A comprehensive range of zirconia crucibles

A long-standing commitment to materials, processes, and applications engineering has allowed Zircoa to develop a range of zirconia crucible compositions, which are designed to maximize the crucible lifetime and minimize melt contamination. These crucibles are optimized for different purposes:

- **Composition 3001**: This magnesia partially stabilized zirconia (MgO-PSZ) exhibits exceptional resistance to thermal shock and erosion. It has low thermal expansion properties and excellent nonwetting characteristics, which makes it an excellent all-around product for casting PGMs. An 1,850°C continuous temperature load and brief overheating of the melt is typical in practice.
- **Composition 1651**: This calcia partially stabilized zirconia (CaO-PSZ) is often the preferred choice for corrosive alloys requiring melt temperatures of 1,900°C and above. This option provides enhanced resistance to erosion under these extreme conditions.
- **Composition 2291**: This yttria partially stabilized zirconia (Y_2O_3–PSZ) is a premium choice with highest inertness at maximum application temperature of up to 2,300°C. This inertness makes it the preferred choice for platinum–rhodium alloys.
- **Composition 2004**: This zirconium silicate, also known as zircon, combines beneficial properties at high temperatures with robust resistance to aggressive glassy or siliceous slags that occur during "dirty refining" applications.

Each of these compositions takes into account the fact that zirconia has three distinct crystal phases depending on the temperature: monoclinic, tetragonal, and cubic. The addition of stabilizers such as magnesia, calcia, or yttria shifts the temperature at which the phase transition occurs. Controlling these transitions is important because they can cause significant volume changes, particularly the transition from monoclinic to tetragonal. (Note: This volume change is very slight in zircon-based compositions.)

To maximize the life of zirconia crucibles, designing the thermal cycle to pass slowly through transition temperatures is recommended because it minimizes the thermal gradients, which can cause localized stress and cracking. Figure 1 illustrates different linear expansions during heating up and cooling down cycles for Zircoa's various compositions. These behaviors dictate the temperature ranges in which the heating and cooling rates must be reduced to give the material sufficient time to compensate for the change in volume (Table 2).

Table 2. Temperature ranges for Zircoa's zirconia crucibles.

COMPOSITION	APPLICATION TEMPERATURE	PHASE TRANSITION TEMPERATURE	
		Heating up	Cooling down
		monoclinic → tetragonal	tetragonal → monoclinic
3001	1,850°C	1,100°C to 1,300°C	1,100°C to 700°C
1651	1,900°C	1,000°C to 1,100°C	950°C to 800°C
2291	2,300°C	700°C to 900°C	750°C to 500°C
2004	1,800°C	1,025°C to 1,150°C	925°C to 800°C

Source: Zircoa

Future zirconia crucible development

Zircoa's mission statement, "Deliver What Matters," reflects the company's commitment since its founding in 1952 to identify and develop solutions that support customer operations and innovations globally. By engineering crystalline structure, stabilizer systems, grain size, and other properties, Zircoa's team can help optimize the performance of future zirconia crucibles based on customer-specific requirements.

About the authors

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