Optimizing Investment Casting for Super Alloys – A Ripple Effect

Improvements in Service Life of Ceramic Melt Containers and Effects on Sustainability

32nd EICF Conference & Exhibition

Città della Scienza | Napoli (Italy)

May 12th-15th, 2024

Presentation Outline

- Zircoa
- Overview of relevant standards
- Case study
- Focus on sustainability
- Zirconia as crucible material
- Best practice and sustainability
- Conclusions

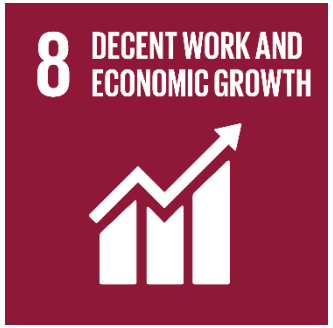
- Zircoa, Inc., USA
  - Headquarters
  - Founded 1952
  - ISO 9001:2015 with Design
- Zircoa GmbH, Germany
  - Sales office EMEA
  - Founded 2012
  - 100% Subsidiary of Zircoa, Inc.

UN Sustainable Development Goals (SDG)

- UN Agenda 2030, from 2015
- 17 Sustainable Development Goals (SDG)
- 169 Targets to be achieved by 2030

Source: https://www.perlon.com/en/sustainability/

UN Sustainable Development Goals (SDG)



Target 8.4	IMPROVE RESOURCE EFFICIENCY IN CONSUMPTION AND PRODUCTION
Target 9.5	ENHANCE RESEARCH AND UPGRADE INDUSTRIAL TECHNOLOGIES
Target 12.2	SUSTAINABLE MANAGEMENT AND USE OF NATURAL RESOURCES
Target 12.4	RESPONSIBLE MANAGEMENT OF CHEMICALS AND WASTE
Target 12.5	SUBSTANTIALLY REDUCE WASTE GENERATION

Source: https://www.globalgoals.org

Overview of Relevant Standards

- Sustainability in Investment Casting (IC):

  Focus on reducing environmental impact, optimizing resource utilization, and ensuring ethical practices throughout the manufacturing process

- What do these contain?
  - Resource efficiency (raw materials / water management)
  - Reduced emissions (raw material and final part production)
  - Supply chain transparency
  - Life cycled assesment / Continuous improvement

- What are the measures?

  Specific metric-based with various ISO certifications upon meeting

- Who is already certified?

  Continual push for raw material and final part manufactures to adopt sustainability standarads

Overview of Relevant Standards

- ISO 14001: Environmental management systems
  - Systematic approach for organization to develop an Environmental Management System (EMS) and continually improve their environmental performance/impact.
  - Follows a Plan-Do-Check-Act (PDCA) cycle for contiunous environmental improvement
- ISO 14040 & 14044: Life Cycle Assesment (LCA)
  - Standardized assement method to compare environmental performance and impact of various products and services
- ISO 50001: Energy management systems
  - Framework for organizations to establish, implement, maintain, and improve an energy management system (EnMS)
  - Effort to improve manufacture's energy performance, reduce energy costs, and demonstrate a commitment to sustainable energy management practices

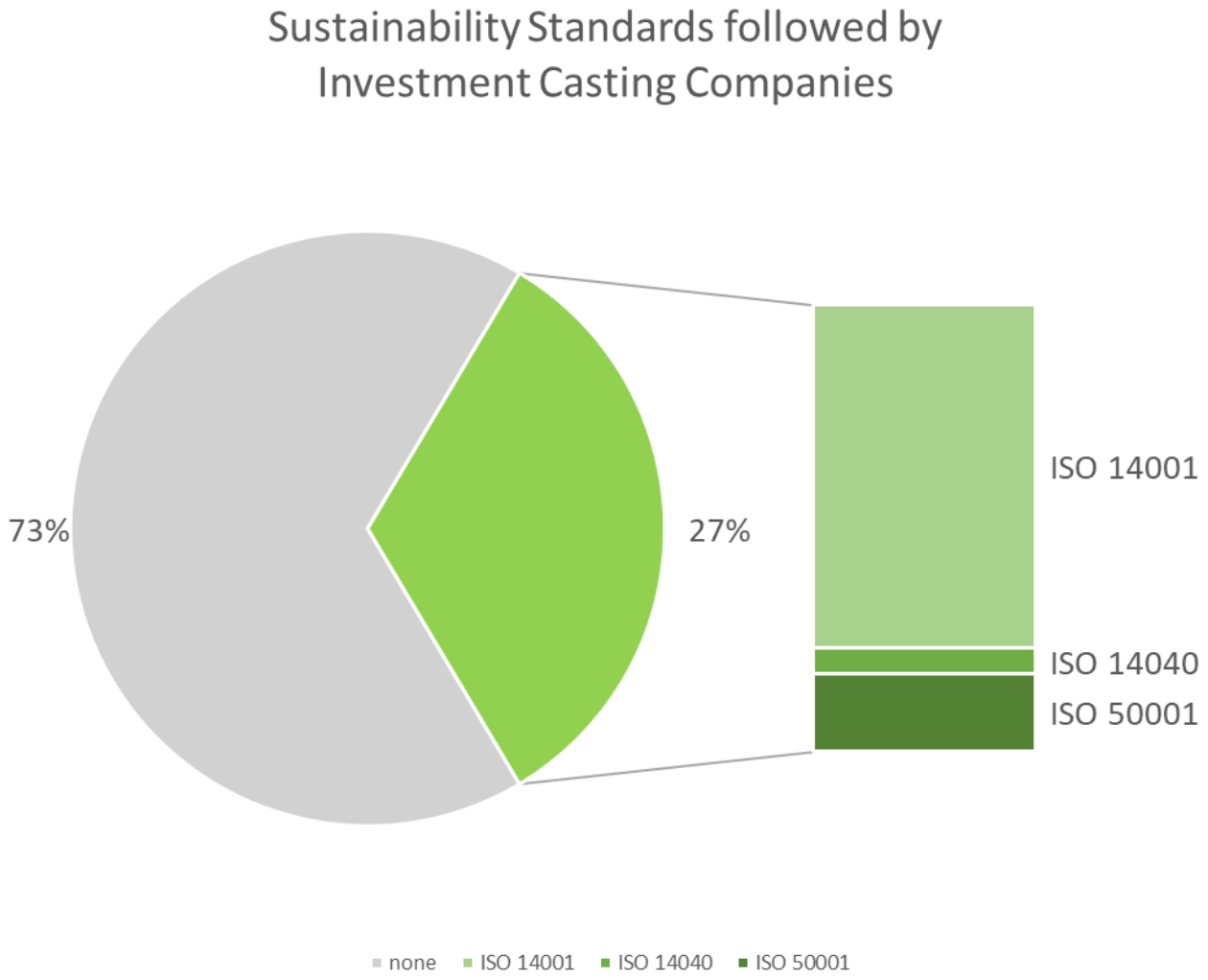
Sustainability Standards in Investment Casting Industry

Review of 146 investment casting company websites[1]

Standards followed:

- ISO 14001: 27 %
- ISO 14040: 2 %
- ISO 50001: 8 %

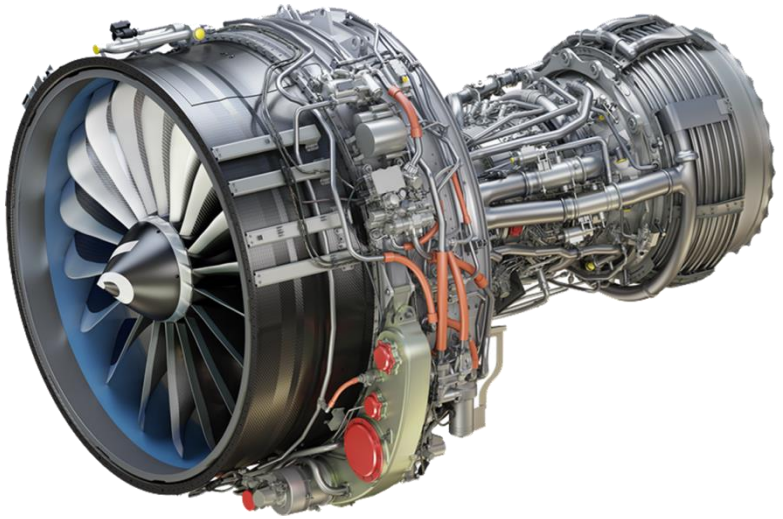
+25 % of reviewed companies follow one or more of the above mentioned sustainability standards



[1] INCAST magazine - Buyers Guide Group / Foundry Issue (Oct 2023, Vol. XXXVI, No10)

Case Study - Introduction

Vacuum investment casting of nickel-base superalloy turbine blades for aerospace/IGT applications….



…to be cast in a melt container,

either liner or crucible

Source: https://www.mtu.de

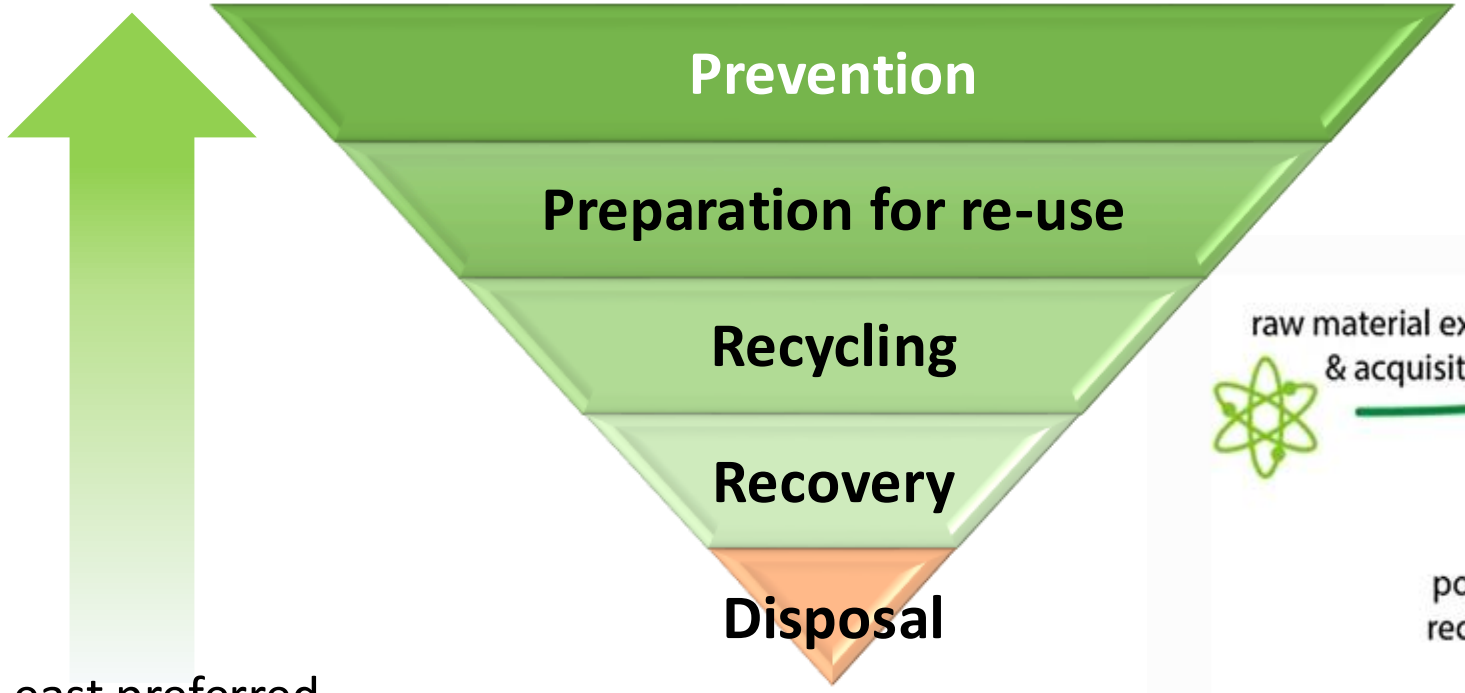
Case Study - Comparison of Melt Containers

	Liner	Crucible
Number of melts	1	15-50
Price per unit	Low	High
Price per casting	Break even ~15 melts	
Logistics	High volume	Low volume
Erosion resistance	Low	High
Thermal Shock resistance	High	Low-medium
Preparation time	Fast	Slow
Casting operation time	Medium	Fast
Flexibility	High	Medium
Casting suitability:		
Equiax	Good	Very good
Directional Solidification	Good	Medium
Single Crystal	Good	Medium

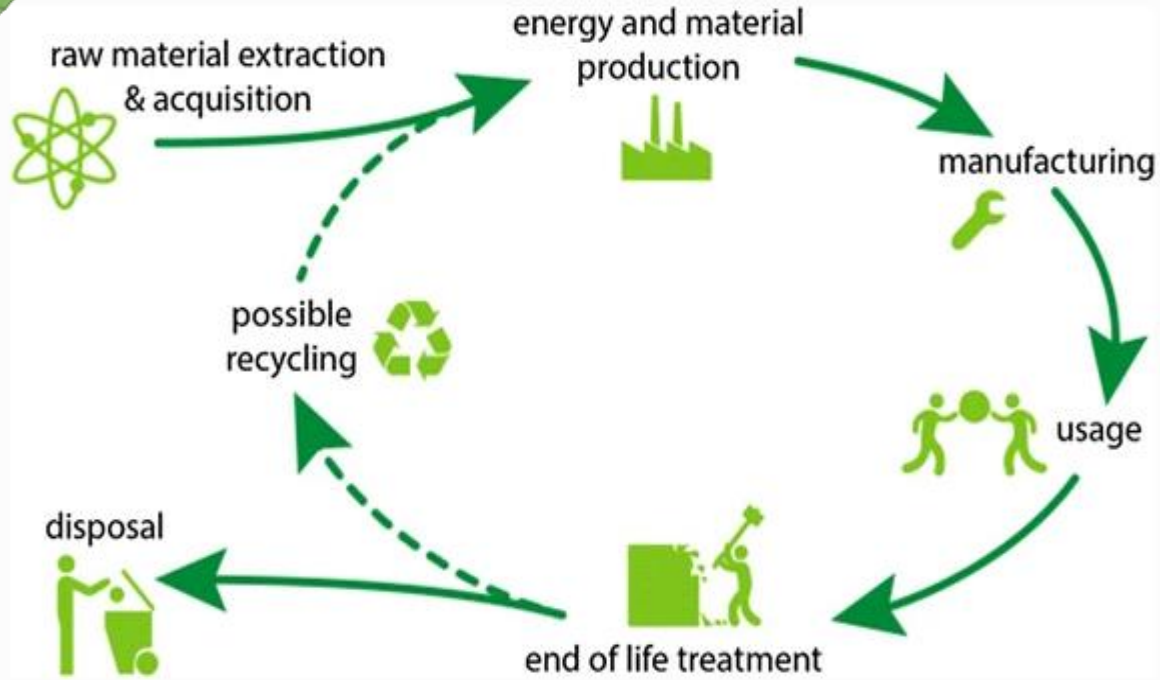
Sustainability Focus - Circular Economy

Waste Hierarchy

Most preferred



Least preferred



Source: Farrelly D (1984) The book of bamboo

Sustainability Focus - Life Cycle Comparison

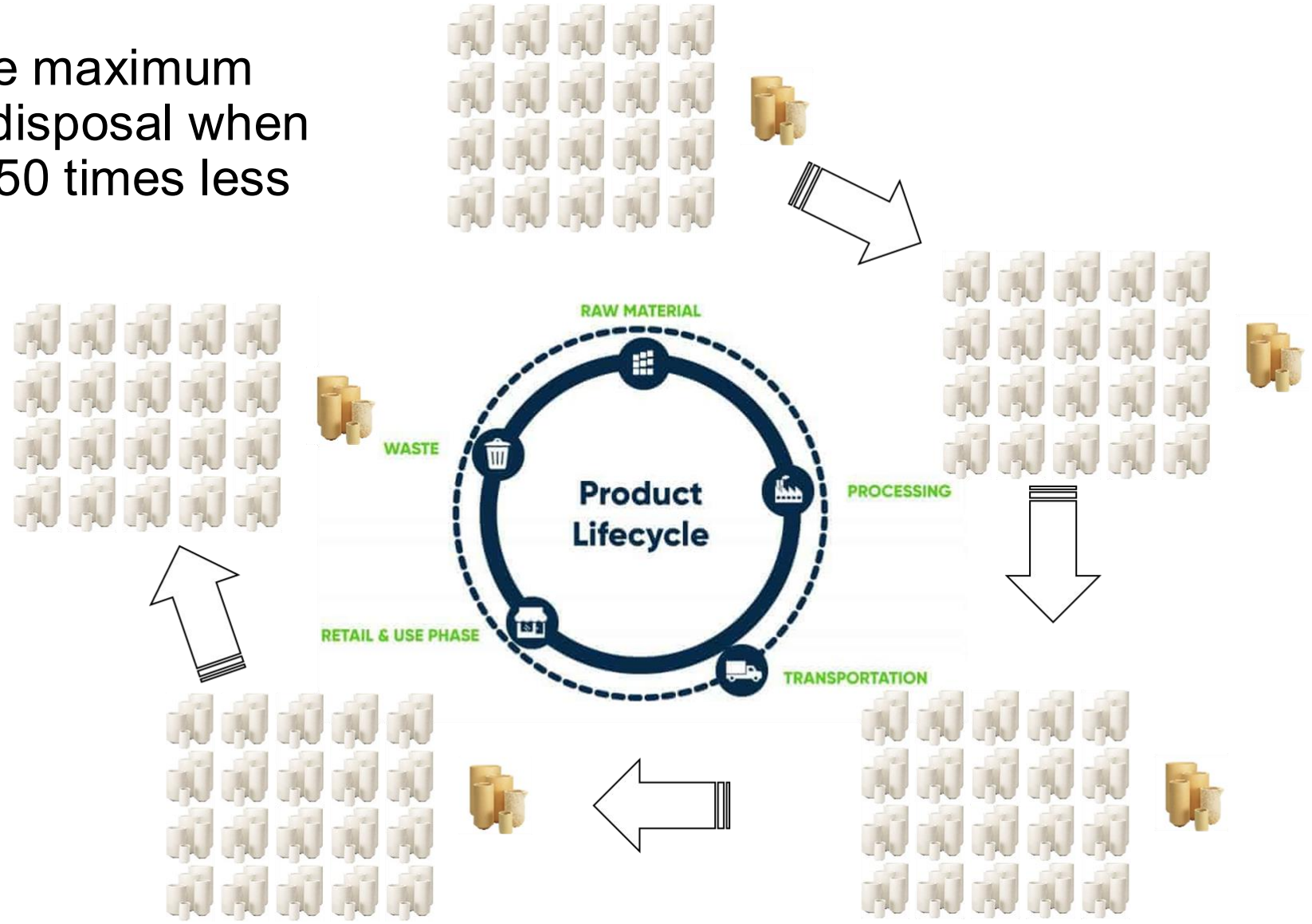
Melt Container Production	Liner	Crucible	Comments / Assumptions
density (g/cm³)	2,4	4,4	Alumina-silicate liner vs. Zirconia crucible
≈14kg melt container (kg)	2,9	5,5	
Mass of material for 20 melts (kg)	**58**	**5,5**	Assume crucible can achieve 20 melts per crucible
CO_2 for RM production (kg)	47,9	2,2	Liner (calcined Al_2O_3 / mined SiO_2), Crucible (mined ZrO_2)
CO_2 for melt container production (kg), 20 melts	16,4	1,5	Firing at 1200˚C for liner and 1700˚C for crucible (2,0kg CO_2 for every m³ of Natural gas burned)
Packaging & Delivery			
Liners/Crucibles per pallet	**144**	**18**	Liners can be packed more economically, (1200 x 800)mm pallet size
Cost to ship liners / crucibles for 20 melts (€)	33,3	13,3	Assume 240€ per pallet for delivery
Transport / Storage volume for 20 melts (m³)	0,13	0,05	Assuming 0,96m³ per pallet
CO_2 Emission for product transport (kg)	49	19	Assuming 500km distance (consumption: 30l/km, emission 2,5kg/l) →1m³ volume
Waste			
Mass of material for 20 melts (kg)	58	5,5	
Cost of disposal (€)	2,3	0,2	Assuming 0,04€/kg
Cost to transport to disposal (€)	1,7	0,7	5% cost to transport to dump vs. part delivery
CO_2 Emission for waste transport (kg)	51	20	Assuming 500km distance (consumption: 30l/km, emission 2,63kg/l) →1m³ volume
Summary			
Estimated Total Cost for 20 melts (€)	**37**	**14**	
Estimated Total CO_2 emissions for 20 melts (kg)	**164**	**42**	

Liner

Crucible

Sustainability Focus - Life Cycle Comparison

Depending on the ratio of the maximum number of melts, the waste/disposal when crucibles can be used is 15-50 times less compared to liners.

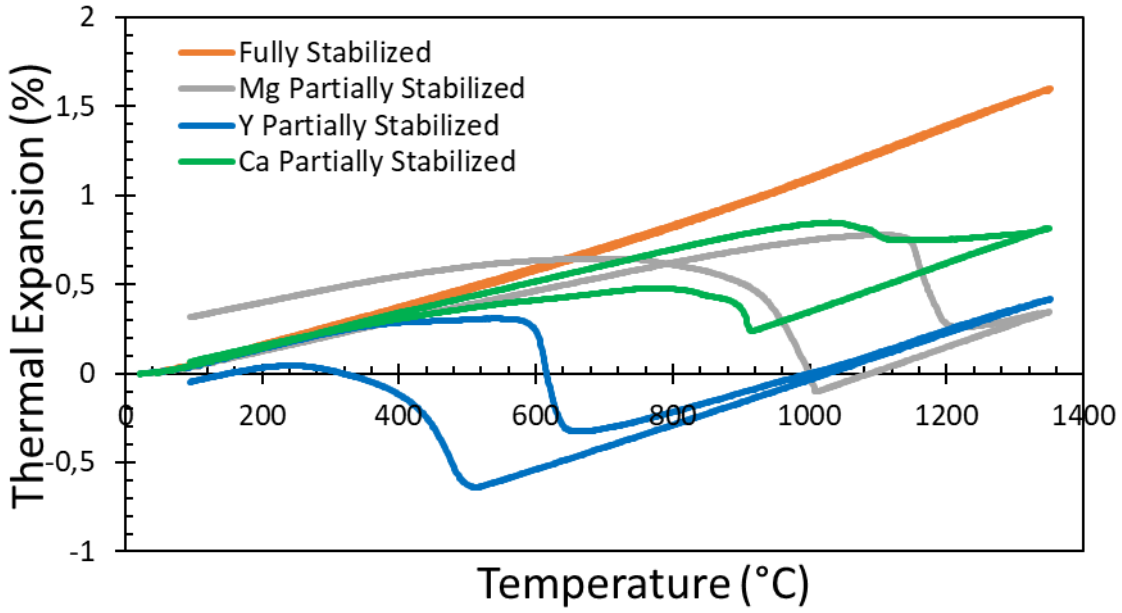


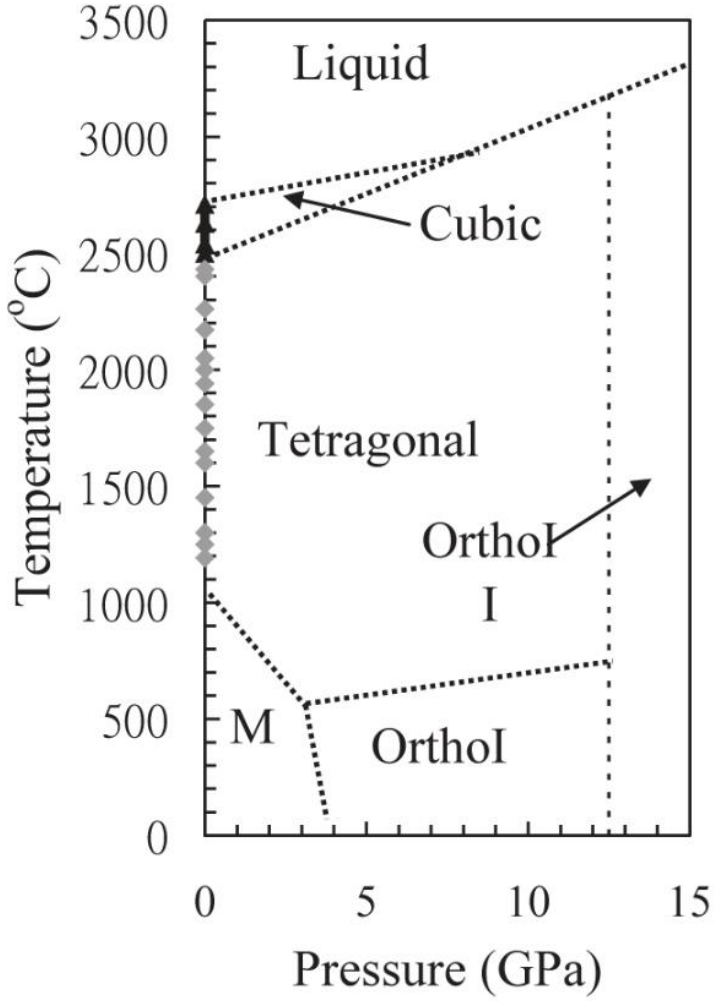
Significant effect on volume of used material/disposal

Source: https://ecochain.com

Zirconia as Crucible Material

- What is zirconia?
  - Zirconium Oxide (ZrO_2)
  - High melting temperature (2715 °C)
- Phase Transition
  - Stabilizers
    - Ca, Mg, Y, Ce
  - Used to control phase transition and thermal expansion

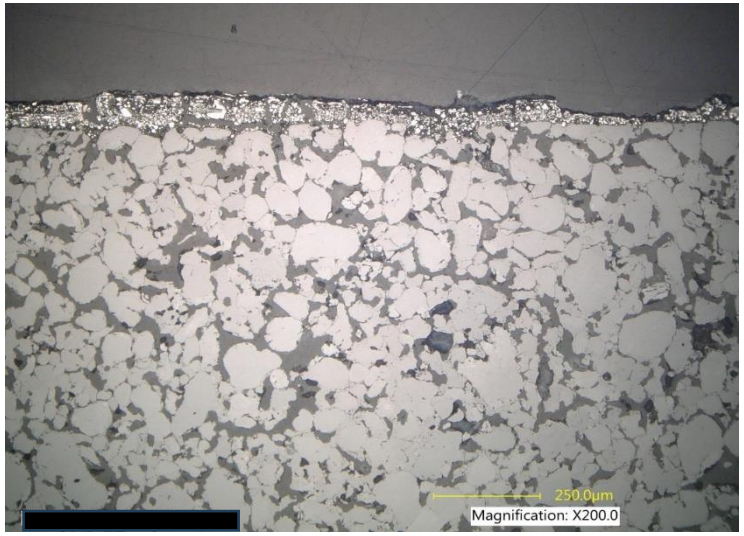


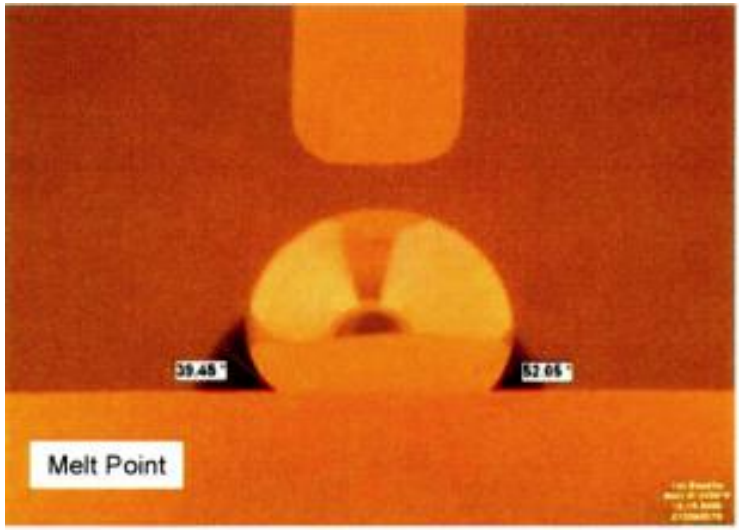


Source: Shackelford, J. F., & Doremus, R. H. (Eds.). (2008). Ceramic and Glass Materials.

Zirconia as Crucible Material - **Typical Use**

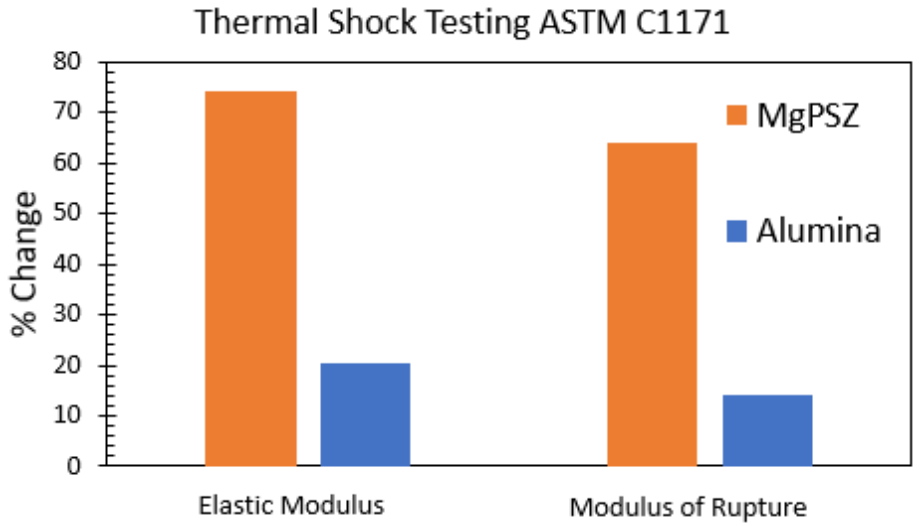
- Common alloys
  - Nickel based superalloy
  - Cobalt based superalloy
- Low thermal conductivity
- High resistance
  - Wetting Angle
    - Zirconia has a high wetting angle with many Ni- and Co-based superalloys
  - Low Reactivity
  - Erosion corrosion resistant

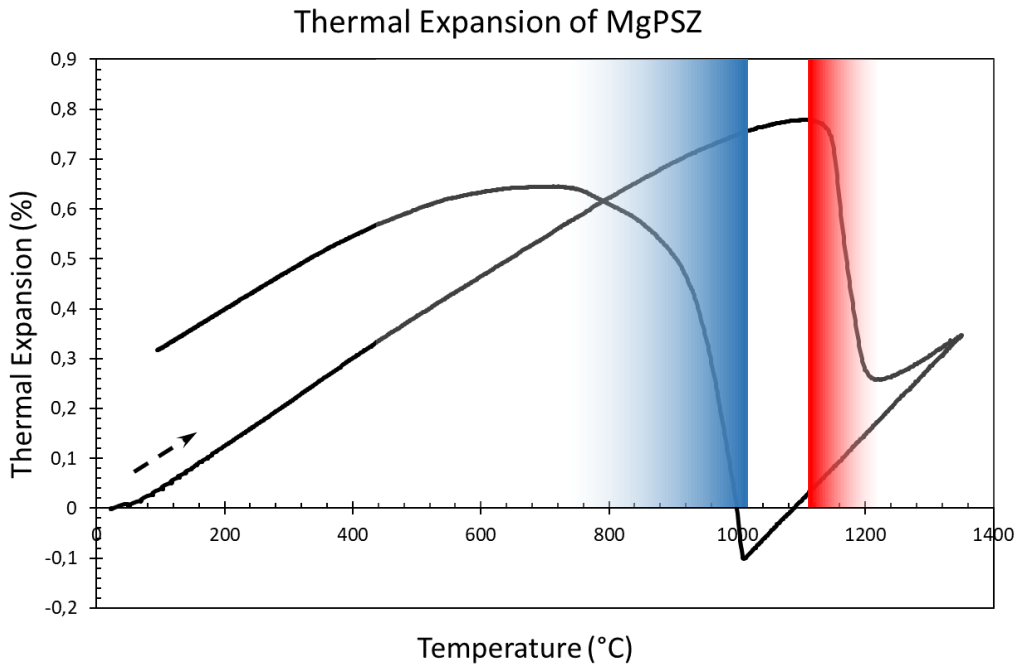




Zirconia as Crucible Material - **Key Considerations**

- Thermal Shock
  - Biggest limitation
  - High thermal expansion compared to other common oxides
- Phase transition and thermal stress
  - Sensitive in thermal handling
  - Improper thermal cycling leads to microstructure weakening
- Cost
  - Zirconia is typically more expensive than other refractory materials





Zirconia as Crucible Material - **Types of Failures**

Large “spalls” on the inner sidewalls

Possible causes
- Billet striking crucible wall during charging
- Extreme thermal shock

Inside bottom cracks

Possible causes
- Billet striking crucible bottom during charging
- The lack of proper bottom support at temperature
- Crucible allowed to cool excessively between pours
- Incorrect type of backup material
- Not enough backup material

Horizontal cracks

Possible causes
- Non-uniform heating or cooling of the crucible
- Too rapid heating during initial preheat cycle
- Insufficient backup support near bottom of crucible

Vertical cracks

Possible causes
- Lack of adequate or proper backup material
- Ineffective insulation near the top of the crucible
- Excessive thermal cycling of pour lip

Zirconia as Crucible Material - **Typical Failure Modes**

- Mechanical damage
  - Damage due to loading of metal ingots
  - Crucible not properly supported
- Thermal cycling
  - Rapid heating and/or cooling through transition temperatures could impact mechanical integrity
- Lack of proper temperature management
  - Uneven heat distribution leads to phase transition induced strain
  - Pour path is not pre-heated leading to cracks along the path

Zirconia as Crucible Material - **Successful Optimization**

- Beneficial
  - Proper installation
  - Sensitive handling / prevention of mechnical stress
  - Considering phase transition related change of volume
  - Consistant casting operation

- Detrimental
  - Extreme temperature gradients
  - Quick temperature changes
  - Inconsistant processes

Zirconia as Crucible Material - **Training and Technical Support**

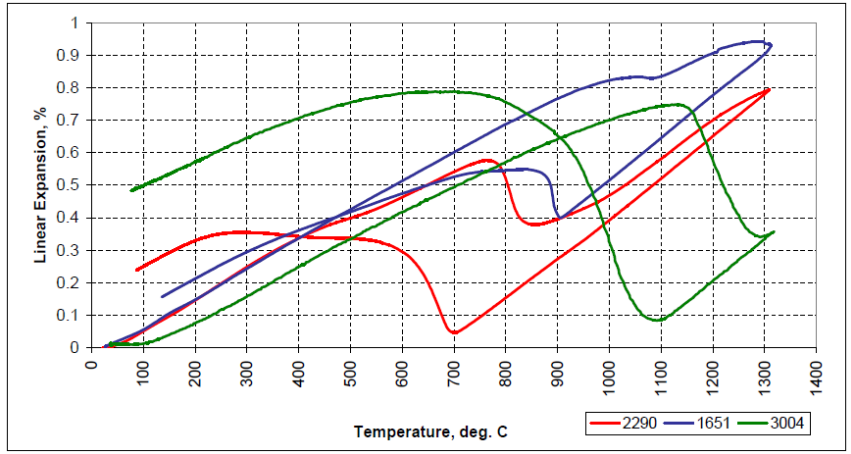
1. Zircoa engineering guide

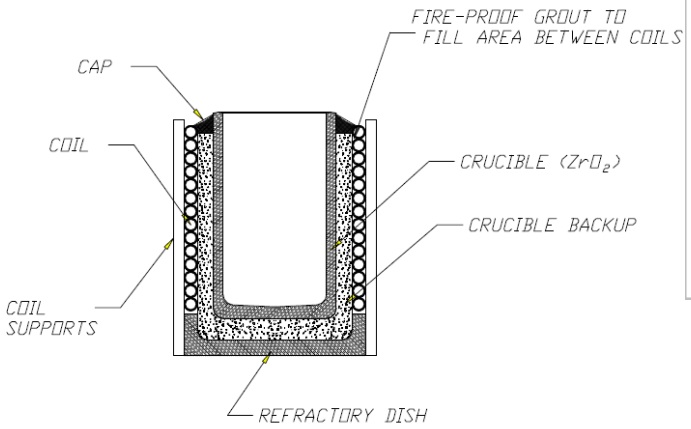
- Best-practice in using crucibles

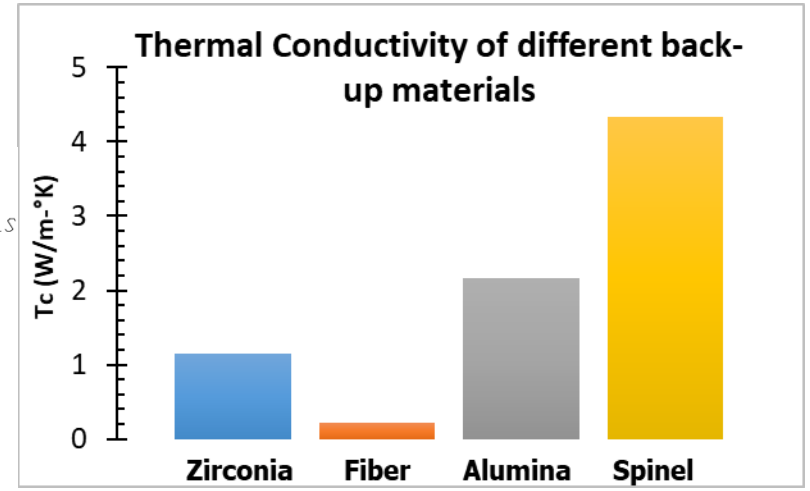
2. Casters Training Workshop

- Practical
  - Training with the casting operation team
    - Best practices for crucible installation and casting operation
    - Discussion of typical situations and potential causes of failure
- Theoretical
  - Technical presentation

Improved sustainability through process optimization







Conclusions

- Growing acknowledgement and adoption of sustainable investment casting practices
- Currently sustainability standards followed by +25% of reviewed group
- Case study: Opportunities for energy and waste reduction
  - Multi use crucibles as a sustainable choice
  - Recycling aspect
  - Best practices and training to realize full potential
  - Automation in support of sustainability initiatives

<u>Ripple effect:</u>

Bridging the knowledge gap on the optimal use of crucibles opens up the opportunity of significant waste reduction

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