Designing with Ceramics

This guide is aimed at engineers and designers wishing to incorporate advanced technical ceramics, such as Syalons or Zircalon, into their design. Often an engineer unfamiliar with using ceramics will want a direct copy of a component that was originally metal, for example, made in ceramic. Very often this is not the best solution and can unnecessarily increase manufacturing costs and even result in the component not working as desired.

This guide will firstly compare the general physical properties of advanced ceramics to metals, polymers and refractories, in order to highlight the major differences that exist between the different material groups. Following this, a series of design tips will emphasize the major points to consider when designing and using ceramic components.

By following these suggestions where possible, the ceramic part will be easier and cheaper to make, saving you time and money, while still delivering a part 'fit for purpose'.

General Materials Comparison

The table below compares some general physical properties of advanced ceramics, with metals, polymers and refractories. These three material types are often replaced by ceramics. The values of *low*, *medium* and *high* are not absolute and only indicate a *general* tendency for a materials group for a particular physical property, as there are such a vast range of materials in each group.

Property	Ceramic	Metal	Polymer	Refractory
Tensile Strength	Medium	Medium / High	Medium	Low
High Temperature Strength	High	Medium	Low	Medium
Elastic Modulus	High	Medium	Low	Medium
Compressive Strength	High	Medium	Low	Medium
Toughness	Low	High	Medium	Low
Ductility	Low	High	High	Low
Hardness	High	Medium	Low	Medium
Density	Low / Medium	Medium / High	Low	Low / Medium
Wear Resistance	High	Medium	Low	Medium
Thermal Conductivity	Medium	High	Low	Medium
Thermal Expansion Coefficient	Low	Low / Medium	High	Low
Thermal Shock Resistance	Low / Medium	High	High	Low / Medium
Corrosion Resistance	High	Low / Medium	Low / Medium	Medium / High

The important points to note from this table are that advanced ceramics, although strong and hard, are brittle and lack toughness, particularly in comparison to metals. They are relatively poor under tensile stresses, although excellent under compressive strength. Due to their complete lack of ductility, ceramics fail suddenly and catastrophically on reaching the critical tensile stress in the region of inhomogeneities in the microstructure. High stresses can occur in the region of sharp edges, corners and holes, for example. On the other hand, advanced ceramics can withstand very high compression loading. This has the effect of closing up the critical flaws in the microstructure. This property should be utilised in a design whenever possible.

With these points in mind, the following design tips should be followed where possible. In addition to giving the component a better chance of giving the performance required, following these tips will also save time and money during manufacture.

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Designing with Ceramics continued…

Design Tips

1. **Tolerance dimensions as loosely as possible**. If a component can be toleranced at ±1-3% for example, the part can usually be produced ‘as-sintered’. This then eliminates the need to diamond grind the component, which is one of the most costly stages of manufacture.
2. **Limit component thickness**. The strength of a ceramic is limited by the size of its largest flaw. The thicker the component the greater the probability of there being a large flaw. Also, remember that advanced ceramics, such as Syalons and Zircalon, are much stronger than refractories, so in a situation where the ceramic is to replace a thick refractory, a much thinner ceramic part will still do an excellent job.
3. **Avoid features which cause stress concentrations, such as sharp edges and corners, sudden changes in cross-sectional area and small contact points**. Sharp edges and corners should be relieved by chamfers, radii or undercuts. If possible use tapers to gradually change cross-sectional area. Provide large contact areas to spread the load.
4. **Keep the component form as simple as possible**. Remember, ceramic components are fabricated by first forming a low density ‘green’ compact, which is subsequently sintered to full density. This results in shrinkage of up to 30%, which for complicated shapes makes tight dimensional control difficult. In some cases, it may be advantageous to change the form of a non-ceramic part of the design in order to simplify the ceramic component. Alternatively, consider using a modular design that is, split the component into several smaller, simpler pieces.
5. **Keep section or wall thickness as uniform as possible**. Large changes in component thickness are another cause of stress concentrations. This can be the case when holes are located off centre, for example. Also, a thin section will densify quicker than a thick section and so warpage or grain growth could occur while the thicker section is still densifying. Grain growth can result in a reduction in strength, and should where possible be avoided.
6. **Avoid unnecessary diamond grinding**. Grinding can cause very high stress concentration, which as mentioned above, can cause flaws. However, by optimising the grinding parameters or by polishing or lapping, this problem can be minimised.
7. **Consider a modular design incorporating a joining technique such as shrink fitting, using adhesives or screw threads**. Shrink fitting works well for example in assembling a Syalon die in a steel case. The greater thermal contraction of the steel on cooling, places the Syalon in compression, which as mentioned above, is the preferred environment for ceramics. Adhesives, with excellent properties up to 1600°C are also an option for joining ceramics such as Syalons and Zircalon. These ceramics can also be mechanically fastened by using a screw thread (both internal and external), for example.

Hopefully these design tips will give you some points to consider when attempting to incorporate advanced technical ceramics in your design.

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