Neutrons explore how to make high-performance materials that behave both like ceramics and metals

New ceramics for jet engines

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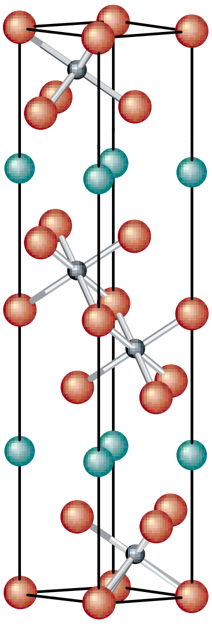
Titanium silicon carbide (Ti_3SiC_2) is a layered material. Its crystal structure, shown left, has double layers of titanium carbide interleaved with single layers of silicon. This laminated structure leads to an unusual combination of properties that is both ceramic and metallic. It is stable at high temperatures, as in the case of ceramics, but also conducts heat and electricity like a metal. Furthermore, because the layers can slide over each other, the material is not brittle like other ceramics and is thus readily machined with ordinary machine tools. Other useful mechanical properties include excellent resistance to sudden changes in temperature, good strength at high temperatures and resistance to oxidation. It is also relatively resistant to fracturing. All these attributes make titanium silicon carbide an excellent candidate material for high-temperature applications such as jet-engine turbine blades.

One drawback, however, is that the material is difficult to make in a pure form. It tends to contain unacceptably large amounts of other compounds – titanium carbide (TiC) and titanium silicides (Ti_xSi_y). This makes it harder, less machinable and difficult to determine the properties of the pure material.

Ceramics like titanium silicon carbide are traditionally made by heating the components, either as elements or compounds, in the correct ratios. However, a large amount of heat is generated in the synthesis of titanium silicon carbide, and this heat of reaction can actually be exploited to make the material. This is called self-propagating high-temperature synthesis (SHS). Once ignited by an ignition source (laser, electron beam, furnace or electric arc), the reaction becomes self-sustaining and converts the reactants to the product very rapidly – in less than 100 seconds.



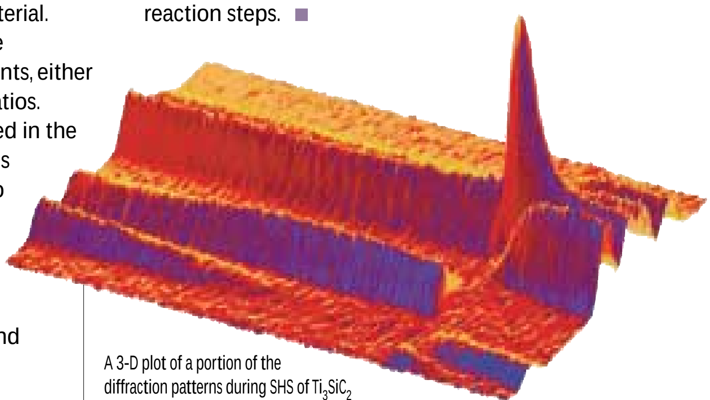
The crystal structure of titanium silicon carbide (Ti_3SiC_2)

Reactions caught in the act

We have been studying SHS reactions in the Ti-Si-C system so as to understand better how to make the pure layered material. Until recently, the extreme speed of the reactions had prevented us from obtaining a clear understanding of the reaction mechanism. However, using the powder-diffraction instrument – D20 – at ILL, we have been able to follow the detailed structural changes as the reaction proceeded.

We first heated cold-pressed pellets of the reactants (titanium, carbon and silicon carbide) in a furnace at a rate of 100°C per minute through the critical range of 800 to 1000°C – to initiate the reaction – and simultaneously recorded diffraction patterns every 0.9 seconds, as shown below.

The SHS reaction proceeded in five stages. Up to 880°C, the reactants simply heat up. Then, there is a change in the crystal structure of the titanium, which goes on to react with the free carbon in the sample. It is this reaction that gives off the heat needed to start ignition. The fourth stage is the formation of a single solid intermediate phase (in less than 0.9 seconds) by the true SHS reaction. It is stable for only about 6 seconds. The reaction temperature was estimated at 2200°C. We believe that the intermediate phase is a solid solution of silicon in titanium carbide which is relatively stable at the combustion temperature but becomes unstable as the temperature drops. The final stage is the rapid development and growth of the product phase, titanium silicon carbide. We are now working on measuring the rates of the different reaction steps. ■



A 3-D plot of a portion of the diffraction patterns during SHS of Ti_3SiC_2 as the reaction progresses (left to right)

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