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Editorial

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High Temperature Structure Materials beyond Nickel Base Superalloy

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Introduction

The higher temperature the engine operates the more power it can deliver. Thanks to the development of nickel base superalloy and enhanced airfoil cooling techniques, the power of jet turbine engine has improved significantly over the last decades. Being the hottest part in the jet engine, the turbine blade has a specific requirement of the materials it used, which includes good mechanical strength, good creep resistance, good stability, and resistance to oxidation. Nickel base super alloy finds critical application in turbine blades due to its many favourable properties. It does not suffer from stress cracking from phase transformation when cycling because nickel maintains its face centered cubic structure from room temperature up to its melting point. It has excellent creep resistance due to its low diffusion coefficient. Nickel metal is also both tough and ductile. Nickel base super alloy takes the advantage offered by nickel and engineers on the alloying addition, where the mechanical properties and oxidation resistance is further improved. However, due to the melting temperature nickel and the presence of low melting phases, nickel base superalloy can only operate at temperatures below 1150°C. The cracking and relative fast growth rate of Al_2O_3 and Cr_2O_3 scale also significantly impairs the oxidation of nickel base superalloy at temperatures above 1200°C. Currently, to bypass the operating limit sets by the nickel base superalloy, sophisticated cooling channels are designed in the airfoil. Airfoil cooling allows engines to operate at temperature above the limitation of nickel base super alloy, but it significantly reduced the engine efficiency. To gain back the efficiency and further increase engine power, new type of high temperature structure materials is in great demand.

The new high temperature structure material must have high melting temperature and good oxidation resistance at elevated temperatures. To satisfy both attributes, one quickly finds Mo-Si-B to be of great potential [1]. In Mo-Si-B, Mo offers the desirable high melting temperature and toughness, boron added silicides offers the superior oxidation resistance and creep resistance. In fact, Mo-Si-B was studied as early as 1950 [2], and is continuously receiving great research attention [3-5]. Recent effects focus on elimination of the deleterious A15 (Mo_3Si) phase, improving creep strength at high temperatures, refining microstructure for improved oxidation, and bypass low temperature pesting oxidation. Other silicides containing materials including Niobium base, Tantalum base, Tungsten base superalloy and et al. or combinations of these superalloys are also a great potential for high temperature structure materials.

In addition to the above mentioned new generation superalloys, ultra-high temperature ceramics, often abbreviated as UHTC are also of great importance to the field of high temperature structure materials. Due to the brittle nature of ceramic, UHTC is currently not under consideration for turbine blades. However, they are rather of critical importance to the application of thermal barrier materials especially for the leading edge and nose cone of hypersonic vehicles. The extreme temperature and environment the hypersonic vehicles experiences calls for materials processing high melting temperature, high thermal conductivity, and good oxidation resistance for structure stability and reusability. Materials like ZrB_2-SiC are currently receiving great research focus for such application [6,7]. ZrB_2 has high melting temperature (3050°C) and high thermal conductivity (ca. 60 W (m K)$^{-1}$ [8]). The oxidation resistance of ZrB_2 is also excellent at temperatures below 1100°C due to the formation of B_2O_3 scale. The addition of SiC offers this materials system enhanced oxidation resistance at temperatures above 1100°C due to the formation of a dense silica scale. To further improve the oxidation resistance, alloy additions such as AlN [9,10], rare-earth oxide, Si, ZrO_2, TaB_2, $TaSi_2$, $ZrSi_2$, $MoSi_2$, TaC, ZrC, and graphite additions have been explored recently [9].

The development of new generation high temperature structure materials such as silicides and borides are still in the early stage of development. This opens great opportunities for researchers to engineer the properties of these materials to meet constant increasing demands. A few research topics are of immediate importance for these materials which includes: near net shape processing for large quantity; enhancing mechanical properties especially high temperature creep; improving oxidation resistance at ultra-high temperatures; minimizing environmental attach especially hot corrosion; enable joining with other high temperature alloys and tuning thermal expansion coefficient; engineering other physical properties like thermal conductivity; and enhancing thermal shock resistance under multiple cycles.

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