

Requirements Engineered into Practice: Ceramic Matrix Composites for High-Temperature Fixtures

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The requirements of a component demand the connection of two kinds of material into a new design using a high-temperature joining process above 1100 °C. The oven concept chosen ensures productivity and process reliability using work piece holders made from ceramic matrix composites.

Using the example of the fibre composite carbon and alumina, it will be shown how defined material properties can be put to use for an industrially proven carrier system. Using engineering, high-tech niche materials are made suitable for standard use, and become an elementary part of the value creation of a new component.

Productivity leads to a new heat treatment concept

The market price for a component is the key driver for productive manufacturing. The market is subject to constant change and this produces progress and innovation. Cost pressure and the demand for increased efficiency in case hardening in automobile gearbox production have led to the one-piece flow concept. The required heat treatment is integrated into the process directly after mechanical soft machining and synchronised with the inflow of soft and the outflow of hard components. This gives rise to treatment of individual parts in a continual flow of parts, which leads to increased productivity compared to conven-

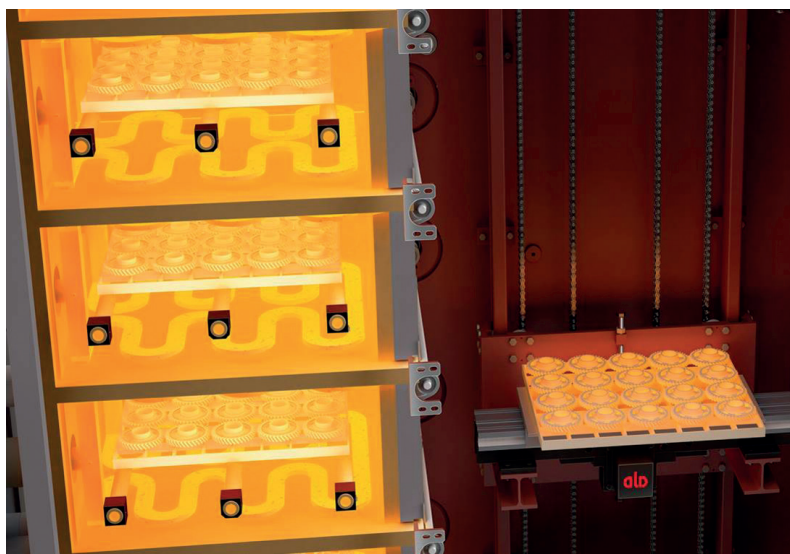


Fig. 1 Multiple chamber vacuum-heat treatment module ALD SyncroTherm® (ALD, Hanau/DE)

tional large batch based heat treatment [1]. The particular feature of this technology is the single layer (2-dimensional) loading of components on a workpiece carrier.

Fig. 1 shows an example of internal rings in a lying arrangement. The temperature and process gas infeed are controlled individually in each heat zone [2]. This facilitates heat treatment adapted to the component, which on one hand shortens process time and thus increases productivity. On the other side, it leads to an increase in component quality in the form of reduced heat treatment delays.

The batch weight per heat chamber for this system is max 50 kg, including the work piece carrier. The time needed for heating up and cooling down is essentially defined by the material of the work piece carrier. In this regard, CFC (Carbon Fibre-reinforced-Carbon) as a carrier material for various gearbox components stands out for various reasons including the fact that heat treatment delays were significantly reduced [3]. For the joining process of vacuum soldering of steel parts here, the CFC critical tempera-

ture of 1050 °C is exceeded. If the metal surface comes into contact with the CFC, carbon is diffused into the edge layer and an eutectic can form at a corresponding temperature.

Consequently, there are local areas of melting, which render the component unusable, and damage the CFC carrier. Therefore, in order to be able to use the benefits of the CFC material, the contact must be secured via mechanical separation. Use of alumin-

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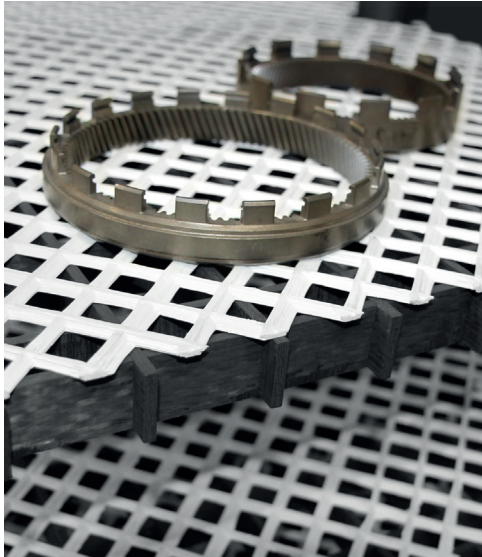


Fig. 2 Alumina fibre composite (WHIPOX®) on C/C-carrier: DuComGrid® (Dual Component Grid)

ium-oxide fibre composite has proved to be a long-lasting process-reliable solution, compared to a coating (Fig. 2).

Ceramic-Matrix-Composites (CMC) to master the specification

The CMC materials CFC (C/C – fibre/matrix) and alumina (Ox/Ox) are recommend for this application, as the following properties can be utilised:

- low density [g/cm³]: CFC: 1,6 / Ox/Ox: 2,7 / cast steel: 7,8;
- high specific strength [Nm/g]: > 1000 °C
- low Thermal Expansion Coefficient – CTE [$10^{-6}/K$]: CFC: 1–8 / Ox/Ox: 4,3 – 8,4 / cast steel: 10 – 20;
- high thermal shock resistance R1 [K]: CFC: 5763 / Ox/Ox: 500 / cast steel: 300.

The mechanical superiority of the composite is evident in the temperature dependent

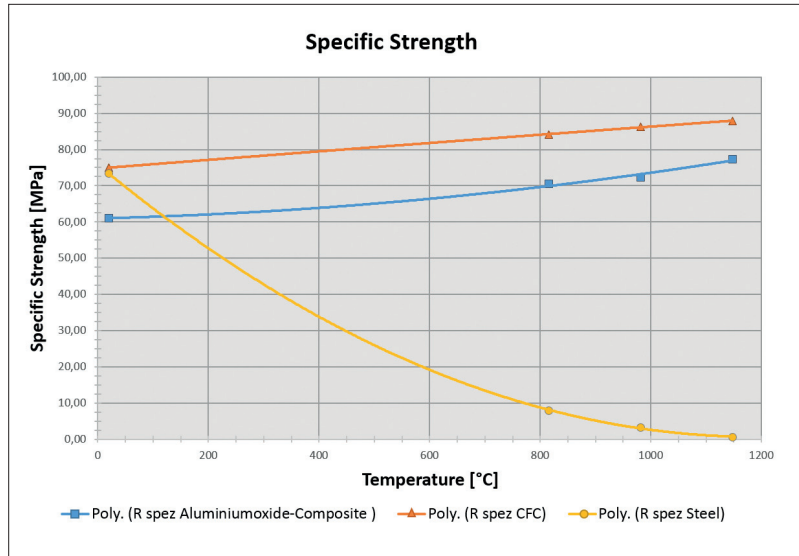


Fig. 3 Specific strength of CFC, aluminium-oxide composite and steel [4]

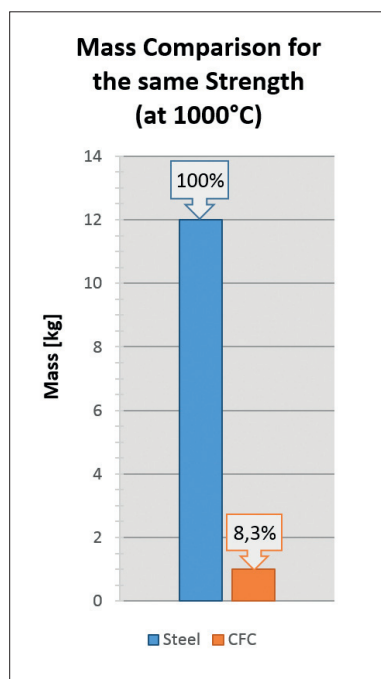


Fig. 4 Weight of steel and CFC for 1 dm³ for strength data at 1000 °C

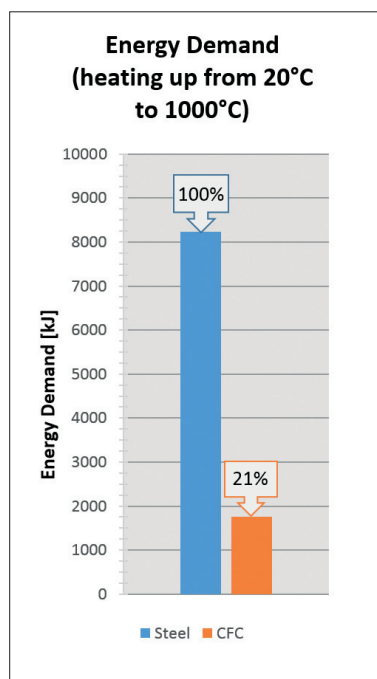


Fig. 5 Energy demand in heating from 20 °C up to 1000 °C for CFC and steel

specific strength. Compared to cast steel, the value for the load-bearing components CFC increases from room temperature to 1200 °C by around 15 % (Fig. 3).

The mass comparison at the same volume (dm³), due to the strength at 1000 °C Fig. 4) shows that the weight of a CFC carrier only contributes around 1/10 of the weight of the comparable steel design. Depending on the component, use of a CFC saves around 60–80 % of mass in practice. This means, slim designs can be accomplished to the benefit of a high piece/carrier weight ratio [5].

The slim design reduces the contact areas and support points of the component and minimises the shadowing from carburisation in case hardening. At node points and other areas of thicker material, significant residual heat is stored, which can be returned to the work pieces.

The reduced “non value creating mass” of the loading device means that warming up and cooling down are even, and faster [6]. Based on the physical data, a CFC carrier only requires around 20 % of the energy of a comparable steel carrier to heat up to 1000 °C (Fig. 5).

If you consider the expansion coefficients of the two materials at 1000 °C (CFC: $1 \cdot 10^{-6}/K$, metal: $12 \cdot 10^{-6}/K$), the CFC structures are stable in form, which means the carrier level and dimensions do not change. Components with a large surface area (hollow gears, Fig. 2) or diameter and wall

thickness differences (waves) are prone to delay. Deformations of the work piece carrier, which are transferred directly to the components, can be ignored with CFC.

Heat treatment processes such as case hardening or quenching and tempering often include enforced abrupt cooling using gas (High-Pressure Gas Quenching: HPGQ) or liquid media (oil, polymer). The work piece carriers are exposed to an extreme thermal shock which is physically described by the thermal shock coefficient $R1 [K]$ for infinitely large heat transfer in initial proximity [7]. Fibre composites are superior to materials with a monolithic structure due to the property combination of fibre and matrix [8]. The properties already listed, strength (flexural strength for CFC and Ox/Ox) and CTE also express the advantages of using CFC as a work piece carrier via the $R1$ -coefficient.

As well as the advantages, there are also limits on composites. In atmospheres containing air and oxygen, CFC can be used up to a maximum of 350 °C, in order to avoid oxidation damage. In a vacuum, or in an oxygen-free atmosphere above 1050 °C, there may be surface reactions where metal and CFC touches (C-concentration, local melting). With regard to alumina composites, the maximum application temperature (1200 °C) should be observed [9].

Engineered solutions by combination

The case here involves a component which arises through the joining of at least two metal components in a vacuum soldering process. The components may not be shown currently for reasons of data protection. The process is carried out above 1050 °C and requires mechanical separation from the CFC surface. The number of parts per furnace run (load pattern) and loading position (lying and hanging) and component variation (geometry and dimension) make CFC the preferred carrier material. Automated loading is envisaged in the further course of process optimisation. The software-controlled positioning on the base requires delay-free component nests over the life-cycle of the carrier.

The permanent, certain separation of contact between metal and CFC on surfaces and edges of the loading device rules out a coating solution. Progress has, indeed, been

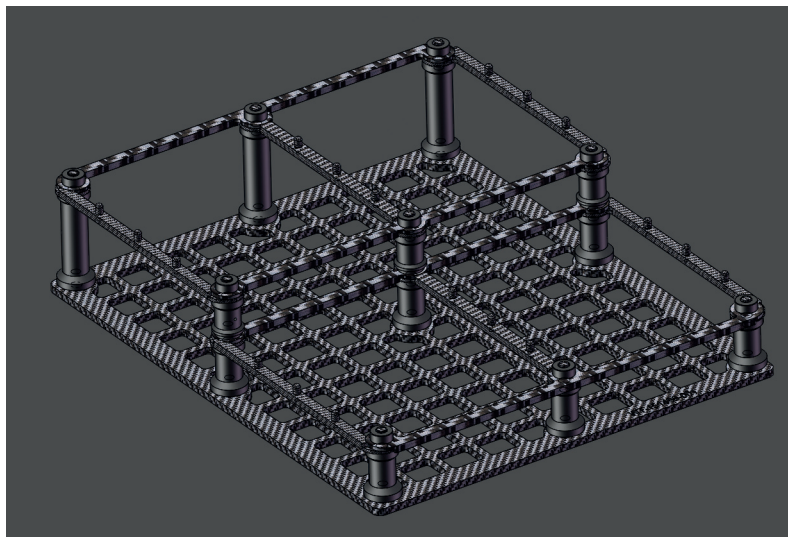


Fig. 6 Basic design of CFC carrier for a soldering process

made in recent years through research and industrial application (Atmospheric Plasma Spray – APS of ceramic powders), however there is still potential in development including adhesion to sharp edges with regard to shock sensitivity [9]. If you validate the cost to benefit relationship for process reliability the APS coats are not competitive in terms of cost compared to the material combination CFC/aluminium oxide composite (Ox/Ox).

From a materials technology viewpoint (materials parameters), the solution for a work piece carrier lies in the combination of both composites. Due to the reliability from various industrial applications, CFC is selected at the carrying element. Experiences from heat treatment, in association with simple

processing (sawing, milling, water spraying) of semi-finished parts (sheets, mesh, pipes) define aluminium oxide composite as the base (separation). The simulation of different designs led to the design as shown in Fig. 6. The variance in component length is assured by supports of different lengths. The oxide ceramic takes over acceptance of the components and is fixed on the CFC strips (Fig. 7).

The ceramic elements are integrated into the CFC structure, with precise positioning. If required, elements may be replaced. The differing coefficients of expansion mean that design measures on the fixing are needed, to ensure the loading of the component base can be repeated accurately in the case of automatic loading.

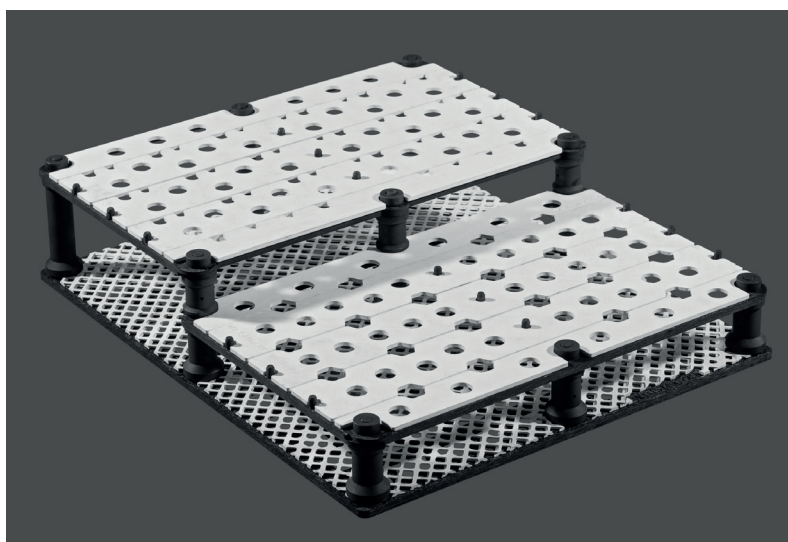


Fig. 7 DuComGrid® carrier, comprising CFC-rack and alumina-fibre composite

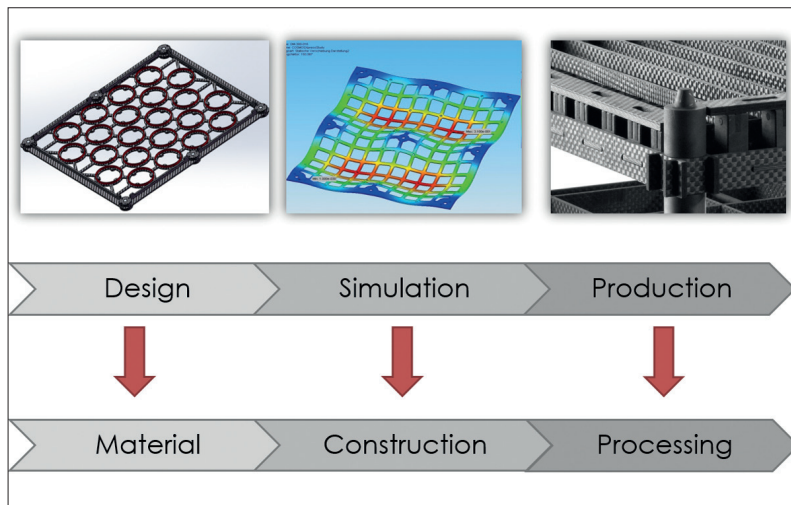


Fig. 8 Engineering as a process of Design – Simulation – Production

Conclusion

Using engineering as a combination of materials technology, design and production, different materials can be functionalised into new components. Progress and development of materials, software (simulation, CAD, CAM) and processing strategies facilitate new design possibilities for combination of materials (Fig. 8).

Both composites have moved out of the high-tech speciality materials niche into what is now a broad area of industrial ac-

ceptance. Semi-finished goods in the form of sheets, pipes and profiles can be processed into components with state-of-the-art technology.

Production at an industrial scale has created reproducible materials parameters for thermal and mechanical simulation of designs. The experiences from a range of different applications have fed back into the engineering, supporting solutions in new areas of application.

References

- [1] Löser, K.: Fertigungsintegrierte Vakuum-Wärmebehandlungssysteme in der Automobilindustrie. elektrowärme international. (2016) [1]
- [2] ALD Vacuum Technologies GmbH: SyncroTherm One-Piece-Flow-Prinzip in der Wärmebehandlung, Prospekt, appeal 027602
- [3] Heuer, V.; Löser, K.; Leist, Th.; Bolton, D.: Enhancing Control of Distortion Through "One-Piece-Flow" Heat Treatment. gearsolutions.com, July 2013
- [4] Graphite Materials GmbH: www.graphite-materials.com. Datenblatt Spezifische Festigkeit
- [5] Terjung, R.; et al.: Vorteile von CFC-Gestellen beim Einsatzhärten im Automobilbau. elektrowärme international (2017) [1]
- [6] Terjung, Rolf. Qualitätsverbesserung durch CFC-Werkstückträger in der Vakuum-Wärmebehandlung. elektrowärme international (2016) [3]
- [7] [https://de.wikipedia.org/wiki/Thermische_Spannung_\(Mechanik\)](https://de.wikipedia.org/wiki/Thermische_Spannung_(Mechanik)). [Online]
- [8] Raether, F.: Ceramic Matrix Composites - an Alternative for Challenging Construction Tasks. CERAMIC APPLICATIONS 1 (2013) [1] 45–49
- [9] COI CERAMICS: Inc. Datenblatt trade name A/N720. 28 June 2017
- [10] Drehmann, R.; et al.: Hochtemperaturbeständige, thermisch gespritzte Diffusionsbarrierschichten auf CFC Leichtbauchargiergestellen. elektrowärme international (2013) [1]