15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 3

Low Temperature Processing of Tungsten-Fibre High-Strength Composite

W.M. Semrau*

*IWS® - Ingenieurbureau Wolfgang Semrau, Innovative Materials- Process- and System development, Corrosion-Protection and Surface-Technique, Bremen, Germany

Summary:

A tungsten nickel/iron compound with a high tungsten content up to over 90 percent by volume of tungsten and an ideal distribution of the nickel-iron multilayer-matrix avoiding tungsten - tungsten interfaces, has been processed without the use of any sintering process and thus resulted in avoiding temperatures of above 700°C during the entire manufacturing process. An electrochemical coating of coarse tungsten powder with alternating layers of nickel and iron and a forging process at temperatures not exceeding 650°C resulted in a high strength compound, which easily could be altered into a tungsten fibre compound with a fibre-length to fibre-diameter ratio of more than 10^3.From the viewpoint of the metallurgist, easier handling systems are obtained when both a liquid phase and high temperatures with their risks for grain structures and grain boundaries are lacking.

Keywords:

MMC, fibre-composite, low temperature processing, tungsten-fibre, multilayer-matrix, electroplating

1. Introduction:

In the field of service applications of high density materials under high dynamic load, certain conditions do demand for an exceptional spectrum of materials properties, consisting of a combination of the utmost maxima of tensile strength, ductile behaviour, resistance against bending perpendicular to the axis of the component and a retarded failure behaviour on mechanical impact. Many attempts have been made throughout the world to meet such requirements, but, as in most technical fields, each time a certain standard

15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 3

seems to settle, new goals and the ultimate necessity to meet them come into sight. This is what we call technical progress. So, development continues.

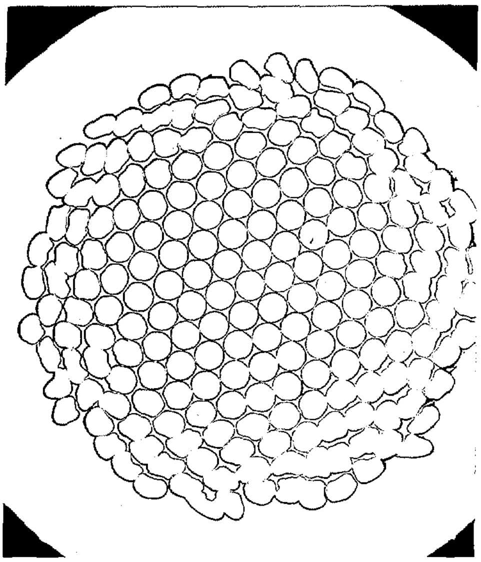
One of the material concepts designed to meet the described requirements was tungsten heavy metals - consisting of tungsten powder, sintered with the aid of some four to ten weight percent of nickel and iron which formed the matrix material. As this material in the sintered condition actually does not meet these requirements, more or less sophisticated measures with an increasing tendency to better improve the material has been taken throughout the years. The actual state of the art is a very sophisticated sintered material with many different treatments following the sintering process which resulted in thermomechanically forged material with a minimum of both inner oxydation and of tungsten-tungsten interfaces between the grains of the material itself.

2. Fibre Reinforced Compounds

Another approach taken to reach the described goal was the transformation of the concept of fibre reinforced materials from the field of extremely lightweight construction materials to the field of tungsten heavy metals.
In order to increase the performance of materials in technical applications, high strength fibres are used to improve the behaviour of low strength materials.
In the field of polymer compounds this method is well established. Well known, not only to technical experts, is the fact that glass fibre and carbon fibre, in high strength applications, reinforced polymer compounds.
To transfer these benefits into the larger field of metallic materials, high strength fibres are used to reinforce metallic materials and their alloys (1). They are usually developed to serve as light-weight high-strength materials. Mostly they consist of ceramic fibres in a ductile matrix and are manufactured by casting, squeeze casting or extrusion. The fibres are intended to provide the high strength required. However, as the volume fraction is generally limited to about 40%, their contribution to the mechanical strength is not so pronounced.
To take advantage of the high strength level of the fibres without having to accept the disadvantages connected with high strength materials, such as brittleness and poor behaviour under dynamic loading, the fibre content should be raised and the matrix properties should be made adaptable to a wide range of characteristics.

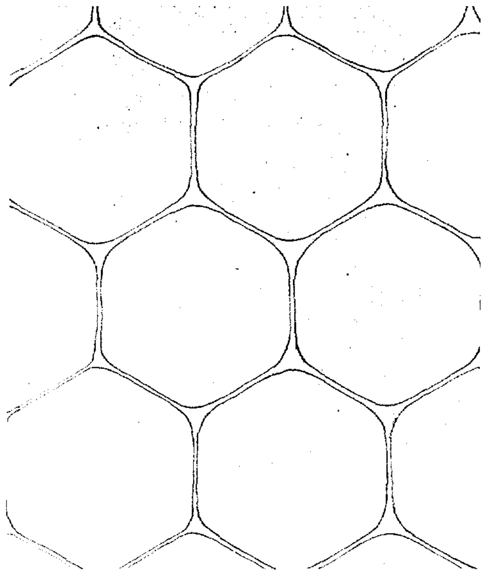
15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 3

In order to meet these objectives and to prove the validity of the basic concept, a model material was designed and manufactured in the laboratory. It consisted of cold worked high strength tungsten wires with tensile strength levels of about 2000 MPa and a metal matrix material which was added by coating the wires by physical vapor deposition (2), or by electroplating (3). Then, the wires were bundled up and compacted by a thermomechanical treatment, Fig.1. This treatment consisted of a forging operation, which bonded the coatings by friction bonding and resulted in a dense microstructure, without pores or holes, Fig. 2. As the highest temperature applied was just above the beginning of recrystallisation of the matrix metal, no liquid phase occurred.



6.5 : 1 non etched

Fig. 1: electroplated wires, compacted by thermomechanical treatment



40 : 1 non etched

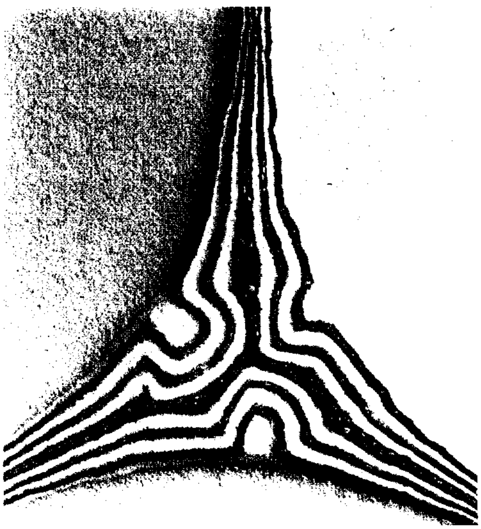
Fig: 2: dense material, compacted by "cold" forging

The fibre content was varied from 88 to 96 percent by volume without affecting the compaction process in a detrimental way. The tensile strength of the fibres could be stabilized at the high level of the starting material. Characterization of the compound by means of static and dynamic testing revealed the matrix to be the weakest link of the system. Ideally, the matrix material should have different properties in different areas relative to the fibre. Therefore, a matrix material comprising a gradient of mechanical properties should be desirable.

15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 3

3. Multi-Layer Structured Matrix

The demand for a matrix material which allowed a gradient of material properties within the matrix itself could be achieved by an electrochemically deposited multi-layer matrix with alternating layers of different metals, Fig.3. Partial alloying by the diffusion process combined with thermomechanical compaction led to smoothing down abrupt changes of prerequisites within the transition zones of the directly neighboured layers. This is one of the important conditions in such a material to avoid high peaks of internal stress which would lead to early failure. By varying thickness and succession of two or three different types of coating metals and temperature and time of application, a widespread field of different characteristics of the matrix material could be produced (4).
As a result, wire / matrix-composites were obtained which exhibited high tensile strength, an excellent behaviour during dynamic bending and a retarded failure mode, showing cracks stopping at interfaces as it is known from wooden structures, Fig.4. Thus, the matrix layers serve as very effective crack stoppers (5).



250 : 1 etched (DIK)

Fig. 3: electrodeposited multi-layer matrix with alternating layers of different metals

Fig. 4: fracture of wire/matrix composite resembling fracture of wooden structures

15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 3

4. Elektroplated Metal Powders

A new coating process allows electroplating of metallic powders. The former coating process to obtain a metallic layer on the surface of metallic powder particles was done by electroless plating. Restriction to layers of nickel or copper electroless plating results in metal/non metal alloys with a remarkable amount of hard phases which are responsible for hardness and corrosion protection; but, they prevent the layers from being processed mechanically after the plating process. The mechanical process includes deformation of the material resulting in brittleness. The advantages of the electroplating process are both the possibility of a wide range of plating metals to be used and of applying different fabrication processes after plating, including mechanical deformation. Multi-layer coating systems could be achieved by the electroplating process (6), Fig.5 and 6.

Fig 5: alternating Ni/Fe-layers on a grain of metal powder

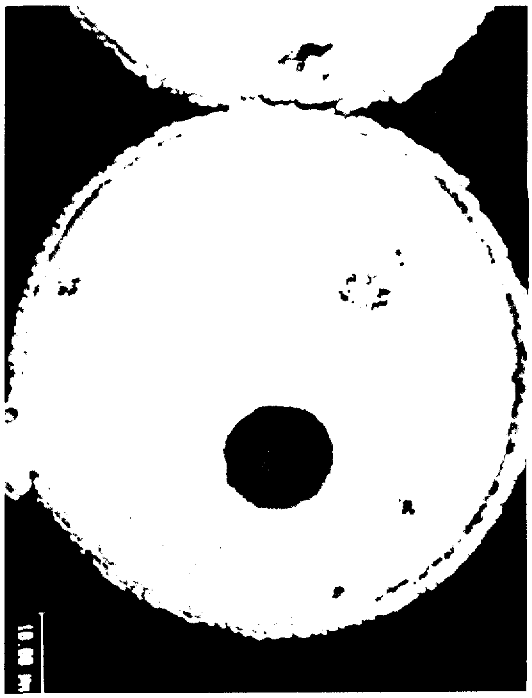


Fig.6: Ni/Cu/Ni- layer on grains of CrNi-steel powder

15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 3

5. In - Situ Formed Fibres

Using coarse metallic powders, the thermomechanical compaction process can easily be extended to reduce the diameter of the powder particles and to stretch the length of them, Fig.7. A length to diameter ratio of $2x10^3$ was already achieved by using a forging process consisting of three steps, ratios of 10^4 to 10^5 should be within reach.
The main profit of the new process compared to the state of the art is manyfold:

avoiding high temperatures and herewith the danger of inner oxidation of the material during the manufacturing process,

each particle of the powder is covered with matrix material and remains so even during thermomechanical deformation, Fig.8. Thereby, in the resulting material no grain- or fibre-interface tungsten/tungsten exists,

easy handling and easy quality management during production, and

low production costs as compared to the state of the art.

Fig.7: fibres, formed during compaction

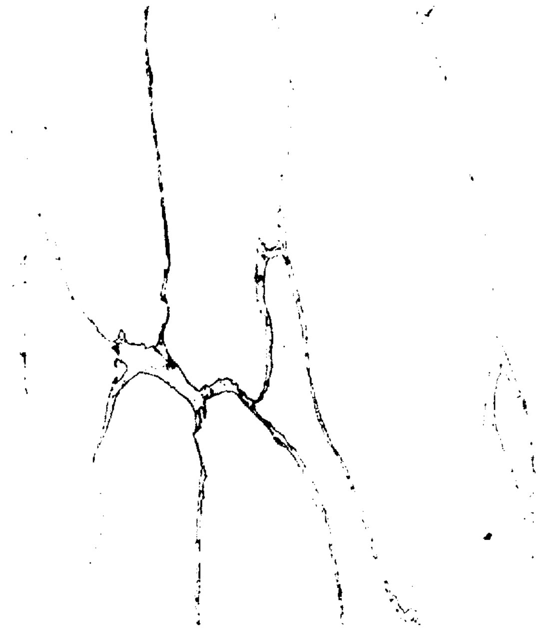


Fig.8: tungsten grains of fine fibre heavy metal, all covered with Ni/Fe-matrix

15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 3

6. Performance and Future Applications

As the new material, even in the laboratory-model wire-version, managed to egalize the performance of the "state of the art" tungsten heavy metal in most respects, the described fine-fibre-version sets a new base for future development in the field of tungsten heavy metals for exceptional service conditions not only limited to penetration purposes.
Multiple possibilities of combinations of matrix material and fibre or grain conditioning opens a widespread field for taylored materials wherever your application demands for contrary material properties.

7. References

(1) E. ElMagd, E.Mokhtar, Mechanical Behaviour of Fibre-reinforced Metals
Current Advances in Mechanical Design and Production, Pergamon Press, 1980

(2) H. Stuke, Fibre-reinforced Compounds with metallic Matrix
IFAM - Techn. Report, Bremen 1984

(3) W.M. Semrau, Tungsten-Fibre metallic Compound with electroplated Matrix
IFAM - Techn. Report, Bremen 1987

(4) W.M. Semrau, CuNiFer-Layers for Seawater Application, composed of galvanically deposited Multi-Layer-Coating
12th Scandinavian Corrosion Congress & Eurocorr`92, Helsinki, June 1992

(5) H. Weiß, W.M. Semrau, Fibre Composites for exceptional Service Conditions, composed of metallic Fibres and electrodeposited Multi-Layer-Matrices
ECCM 8 European Conference on Composite Materials, Naples, June 1998

(6) W.M. Semrau, Coated Metal Powder and Method for producing the same
published application, DE 19823341 A1, Munic, December 1999