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MICROSTRUCTURE OF UNIDIRECTIONALLY SOLIDIFIED FIBER REINFORCED COMPOSITES

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ABSTRACT

During the technical development of our age, higher and higher are the requirements on the applied materials. Composites – used more and more frequently in the last decade – provide a unique possibility of creating appropriate materials for all kinds of usage. Thus, these artificially or in situ produced materials are widespread in aircraft production, space and motor industries as components having special properties.

The mechanical properties of composites are in tight connection with their microstructure, which is determined by the method of manufacturing. An important class of composites is the fiber reinforced ones'. This paper deals with the microstructure of unidirectionally solidified fiber reinforced composites. Samples were made by pouring Al melt between tungsten fibers. The probes were unidirectionally solidified to have the structural anisotropy caused by not only the fibers, but the matrix, too.

The dendritic structure of the matrix was analyzed by a semi-automatic image analyzer; the effect of the fibers on the morphology of the resolidified structure was examined.

Key words: dendritic structure, fiber reinforced, image analyzer, mechanical properties, unidirectionally solidified.

PRODUCTION AND THE MICROSTRUCTURE OF THE SAMPLES

The continuous fiber reinforced composites were manufactured by pouring the melt into a preheated preform. Stainless steel plates perforated by laser beam were fixed on both ends of the preform. The 0.1 mm diameter W fibers were threaded into the approximately 0.2 mm diameter holes of the plates. The composites were unidirectionally solidified at 5 different rates in a Bridgman-type furnace to ensure the directionality of the matrix. This type of – so called – gradient furnace makes it possible to control the morphology of the dendritic structure by separation of low and high temperature parts of the furnace.

Measurements were carried out on several Al samples without fibers, in order to specify the effect of the fibers on the morphology of the matrix under dendritic solidification. Light micrographs of longitudinal and cross-sections of the obtained structure can be seen in Fig. 2.

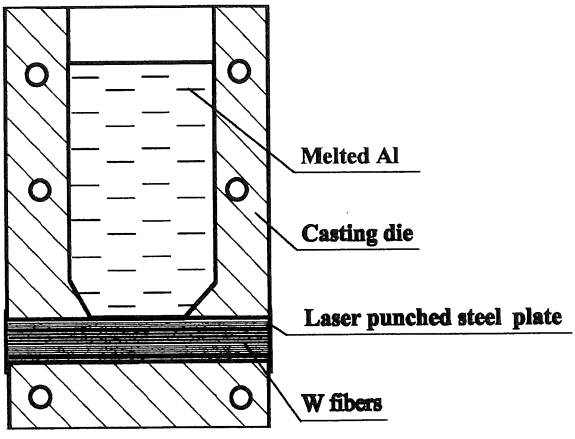

Fig. 1. Casting die used of composite production

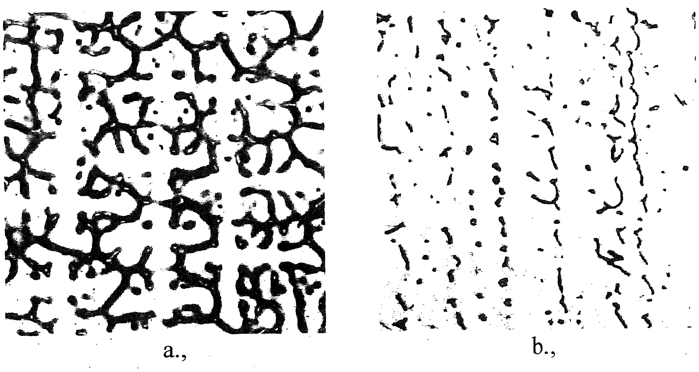

Fig. 2. Dendrite structures arised by unidirectional solidification cross (a) and longitudinal (b) section, N=20x
v = 0.064 mm/s

DETERMINATION OF THE PRIMARY AND SECONDARY DENDRITE ARM SPACING

Characterizing dendritic structures primary and secondary dendrite arm spacing is an important property. The ideal structure of a dendrite can be seen in Fig. 3. (Gácsi, 1994). λ_1 is the primary, λ_2 is the secondary dendrite arm spacing; d_0 is the radius of the trunk of the dendrite; A, B, C are the surfaces of the dendritic arms.

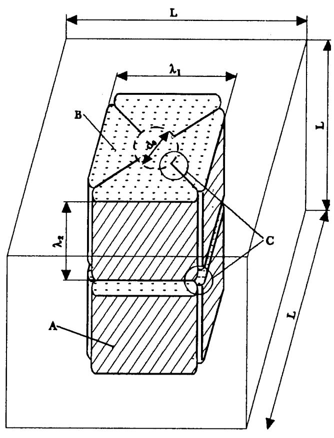

Fig. 3. The ideal structure of the dendrite

where: λ_1 *:primary dendrite arm spacing*
λ_2 *:secondary dendrite arm spacing*
d_0*: radius of the dendrite trunk*
A,B,C: the surfaces of the dendrite arms

Determination of primary dendrite arm spacing by image analyzer can be carried out in several ways. The common feature of these procedures is that one of the characteristic dimensions of the dendrites must be measured in a planar section (number, area, perimeter, length or width of the segments). Determination of primary dendrite arm spacing was performed by a Quantimet 570C image analyzer. A macro was written to find the boundaries between dendrites in order to separate them. Thus characteristic parameters of each dendrite became measurable. The macro executes the following procedures in turn: Autocontrast, BTopHat, FillBoth, Detect, Close, Skeleton, Prune, Dilate, Skeleton, Prune, Binary Edit, Copy Invert, Keep, Measure Feature. These steps make it possible for the image analyzer to complete the locally defective boundaries of the dendrites. Since the boundaries can be seen for the most part and only short distances have to be compensated, the obtained contours correspond to the true boundaries.

Measuring feature parameters the program determines the area, the perimeter, the length and the width of the dendrites. On the basis of the measured data, the primary dendrite arm spacing of the composites plotted against front rate of solidification can be seen in Fig. 4. Comparison of the primary dendrite arm spacing in case of the composites and the samples without fibers can be seen in Fig. 5. The diagram shows that the values are independent of the presence of tungsten fibers.

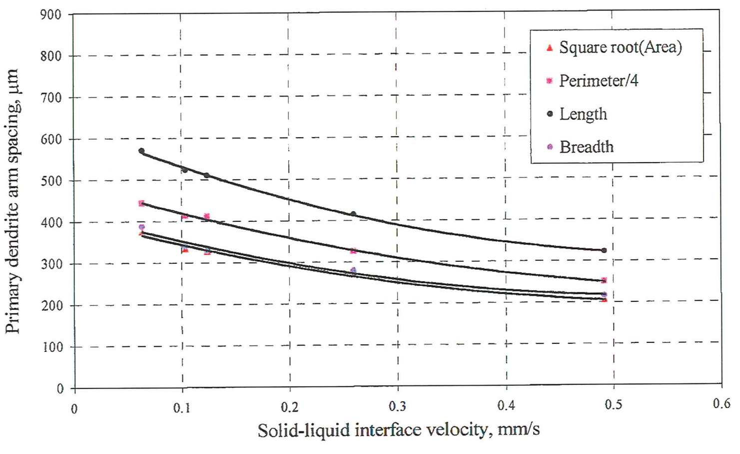

Fig. 4. Primary dendrite arm spacing in the composite samples

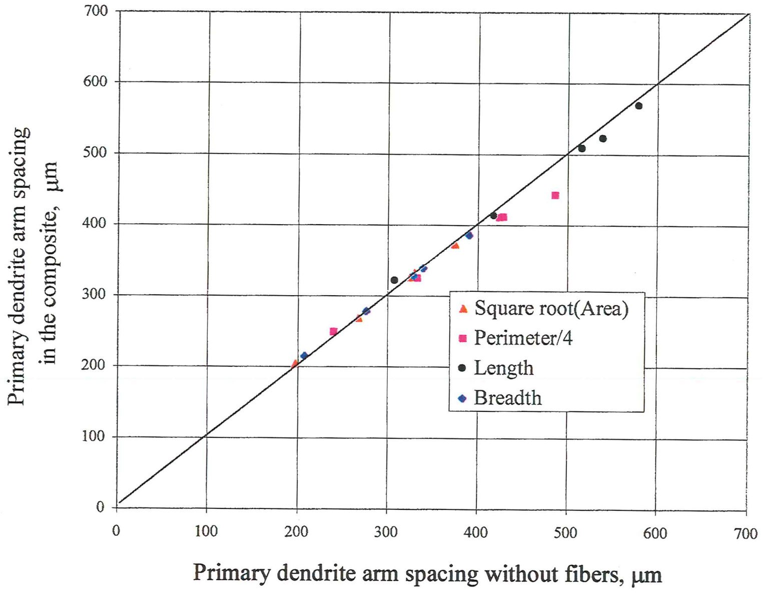

Fig. 5. Comparison of primary dendrite arm spacings

The values of primary dendrite arm spacing are different depending on the applied parameter (square root of area, fourth of perimeter, width, length), but plotting these values against growth rate of solidification the obtained functions are similar to each other.

DETERMINATION OF SECONDARY DENDRITE ARM SPACING

The secondary dendrite arm spacing was determined on the longitudinal sections of the samples, with the aid of an image analyzer. The width of 5-10 secondary dendrite arm was measured simultaneously. Calculating the mean width of the dendrites the average distance of their centerlines were obtained. The results can be seen in Fig. 6. λ_2 values measured on the composite probes are 13% higher on average than on samples without fibers. The difference is probably caused by the smaller heat conduction of tungsten fibers than Al.

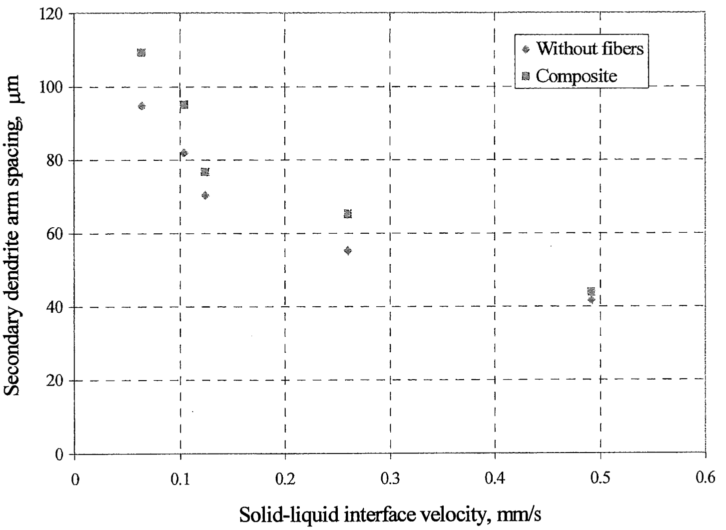

Fig. 6. Variation of secondary dendrite arm spacing with solid-liquid interface velocity

DETERMINATION OF THE SURFACE AREA PER UNIT VOLUME

A macro - similar to that mentioned above in connection with primary dendrite arm spacing - was written to determine the surface area per unit volume. The difference was that in this case not only the separated dendrites were measured, but the perimeter of the arms in the whole field. The average perimeter per unit area of the field (k_A) equals the surface area per unit volume (DeHoff, 1968.)

$$S'_v = k_A \tag{1}$$

Ideally the surface area per unit volume can be calculated from the primary dendrite arm spacing measured on separated dendrites (Underwood, 1970.):

$$S''_v = \frac{4}{\lambda_1} \tag{2}$$

The values of surface area per unit volume measured on the composites and the samples without fibers calculated in accordance with these two methods can be seen in Fig. 7. The difference between the results may be caused by the tertiary arms. Tertiary arms grow parallel with the primary ones, so they are measured when evaluating the planar section of the samples. tertiary arms are smaller than the primary ones: this causes larger values of surface area per unit volume.

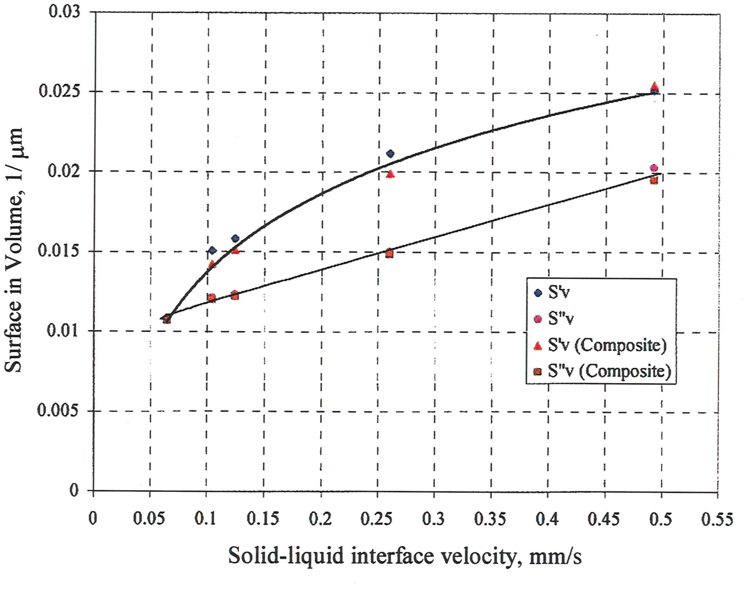

Fig. 7. Measured values of surface in volume

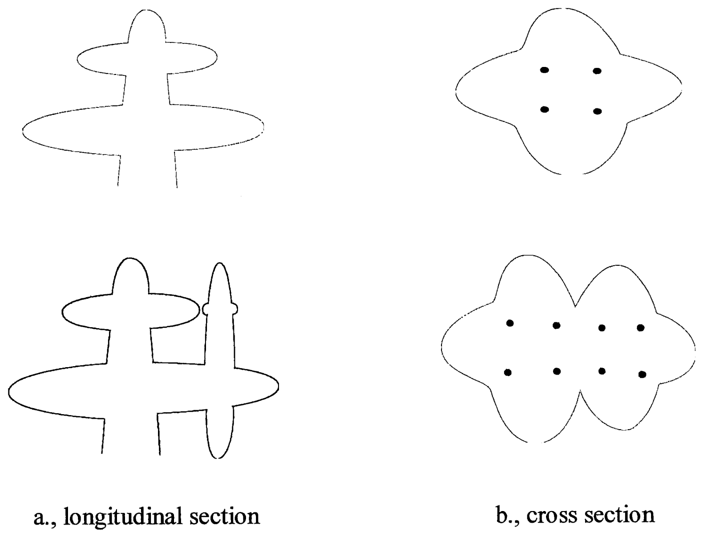

Fig. 8. The primary and tertiary dendrite arms

CHARACTERIZATION OF THE LOCATION OF THE TUNGSTEN FIBERS

Mechanical properties of fiber reinforced composites are strongly affected by the distance and location of the fibers. In case of unidirectional solidification the presence of fibers may influence the course of solidification.

The distances of particles are calculated from the average number of particles per unit area. In such cases it is assumed that the arrangement of particles is regular square or hexagonal, or random. This condition is rarely satisfied and the interpretation of the result is just an average distance. So the arrangement of fibers was characterized by a method previously described by the authors (Csepeli, 1995.). It can be stated that the disorder of the fiber locations in the cross-sections is higher in the unidirectionally solidified sample than in the preform.

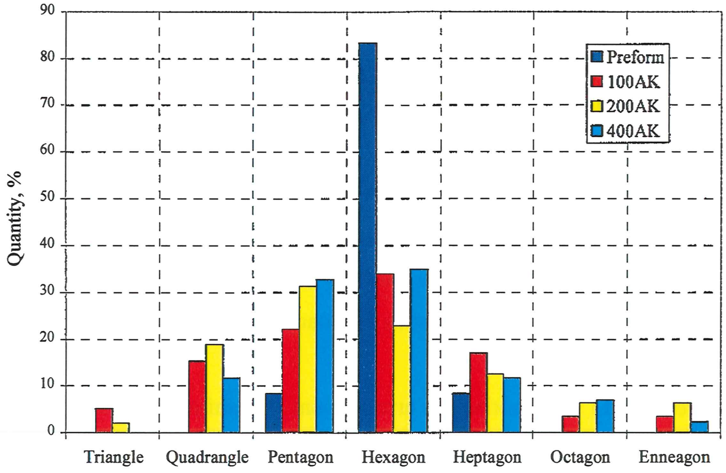

Fig. 9. Characterization of arrangement of wolfram fibers

SUMMARY

Composites used more and more extensively involve the important group of continuous fiber reinforced metal-matrix composites. Beside the strengthening phase, unidirectional solidification can make the matrix unidirectional, too. The properties of the product obtained so are functions of the microstructure of the material, so it is desirable to know. Since there is just a few data available in the scientific literature in connection with the microstructure of unidirectionally solidified continuous fiber reinforced composites, it was an urgent necessity to fill the gaps.

A procedure was developed to characterize primary dendrite arm spacing, which unambiguously determines the boundaries of separate dendrite arms on a light micrograph of a cross-section of the probe. Hence, it is possible to measure the parameters characterizing the morphology of dendrite arms with the aid of image analyzing procedures.

On the basis of the measurements it can be stated that the existence of fibers in a composite has no effect on the primary dendrite arm spacing, but the values of secondary dendrite arm spacing measured on composite samples are higher than those without fibers.

The values of surface area per unit volume calculated from the distance of separate dendrites and from average perimeter per unit area are different, which can be attributed to two phenomena. The first is that during the solidification process tertiary dendrite arms come into being, some of which grows as a primary dendrite arm and can be seen on a cross-section beside the original primary arms. Therefore measuring on the whole section the result is different from that calculated from separate primary dendrite arms. The second reason is that the morphology of primary dendrite arms is a function of the solidification parameters, so the model assuming ideal dendrites provide just an approach of the real values of surface area per unit volume.

The method developed to characterize the arrangement of reinforcing fibers has shown that the fibers of originally almost regular layout became disordered affected by the casting and solidification.

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