DIRECTIONAL CREEP BEHAVIOUR OF MAGNESIUM MATRIX COMPOSITES REINFORCED BY ALUMINA FIBRES

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ABSTRACT

Creep behaviour of two metal matrix composites with magnesium alloy AS21 matrix reinforced by fibres or fibres&coarse SiC particles were creep tested with the aim to investigate the influence of the orientation of stress axis to the planar distribution of fibres in the composites. Strong dependence of time to rupture and minimum creep rate on the orientation was observed in both materials. A specific form of the creep rupture pattern of ruptured specimens was observed and discussed.

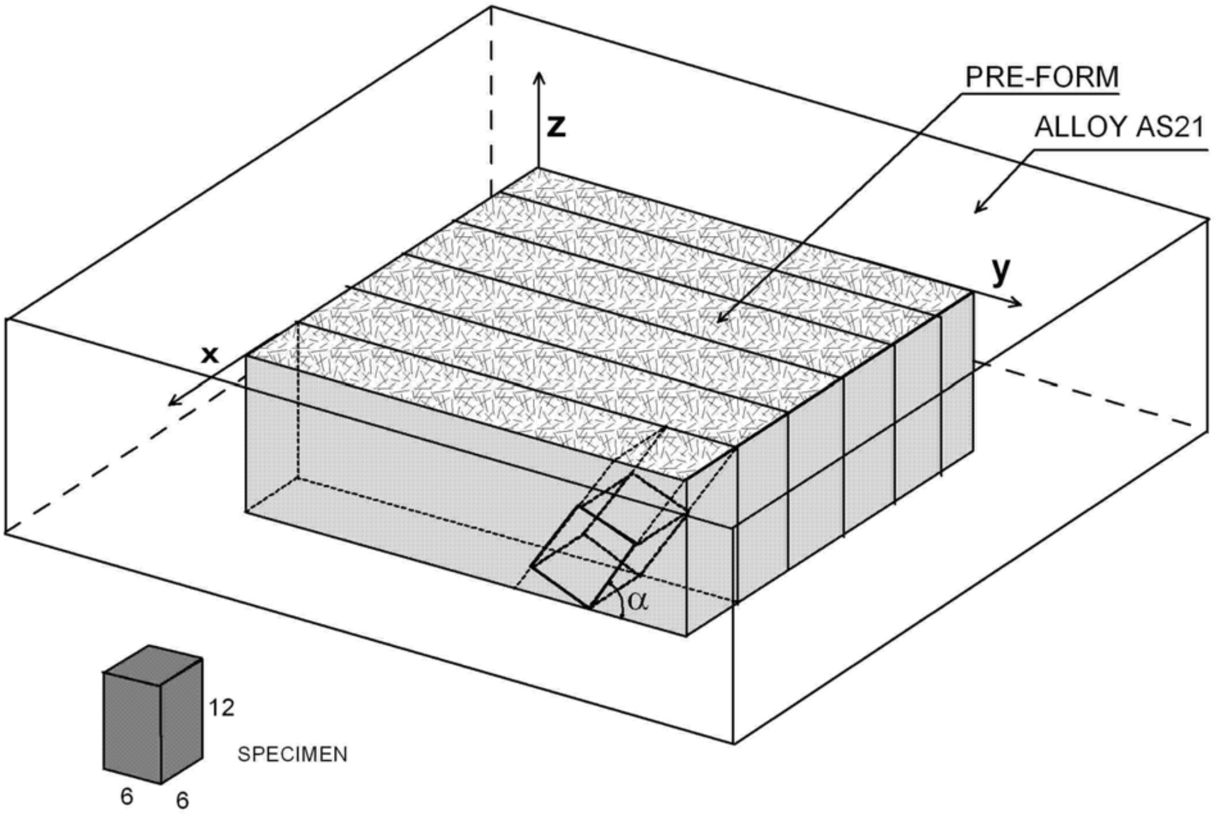
1. INTRODUCTION

Metal matrix composites (MMC's) reinforced by any distribution of fibres mostly exhibit a non-isotropic structure; the fibres are usually in some extent ordered in the volume. As a typical example of such MMC's, the widely used magnesium or aluminium alloys based composites with fibre or hybrid pre-forms, prepared by squeeze casting, can be considered. The original semi-ordering of fibres into random planar distribution remains saved also in the cast products. Due to ordering of fibre distribution, mechanical properties should differ in different geometrical directions of the final product. Up to now, only several papers, e.g. [1 – 3], have dealt with this influence on creep behaviour. Moreover, only the behaviour in three main directions related to the shape of fibre pre-form was investigated in these papers. However, knowledge of a more detailed influence of the structure anisotropy on creep characteristics could be very useful for any verification of various up to now suggested models of deformation of this type of MMC's. Some results showing the influence of the stress axis orientation to the plane of fibre distribution on creep properties of two MMC's with a magnesium alloy AS21 are given in the present paper.

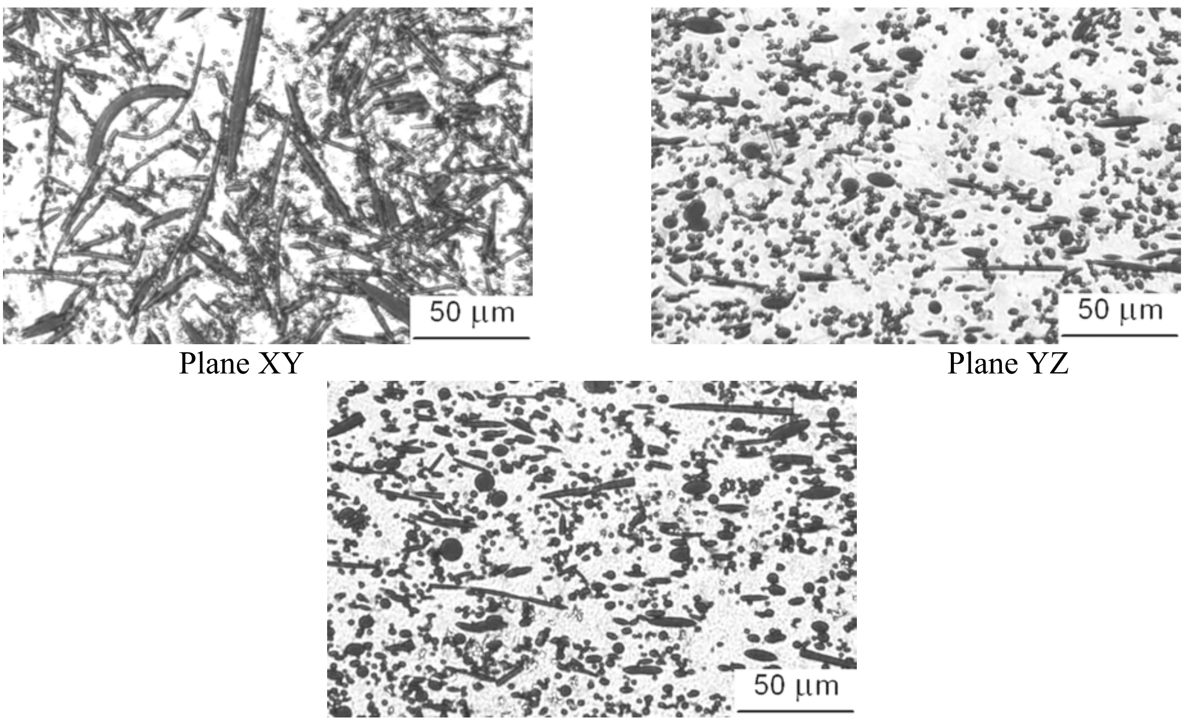
2. EXPERIMENTAL

For experiments, two magnesium alloy AS21 base composites were used. The chemical composition of the matrix alloy was (in wt. %): 2.2 Al, 1.0 Si, 0.1 Mn and Mg balanced. Two composites were prepared by squeeze casting in the Zentrum für Funktionswerkstoffe, Clausthal-Zellerfeld, Germany. For the first composite (in what follows AS21_F), a fibre pre-form was used with nominal content of 25 vol. % of Saffil fibres. The second composite (AS21_H), contained a hybrid pre-form with nominally 5 vol. % of Saffil fibres and 15 vol. % of coarse particles of SiC. The cast blocks had roughly parallelepiped shape with dimensions approximately 50 × 90 × 90 mm. Both pre-forms had a shape of rectangular parallelepiped 25 × 70 × 70 mm and were situated at the centre of the bottom of the blocks (see scheme in Fig. 1).

Fibre pre-form in AS21_F consisted of planar randomly distributed δ - alumina fibres. The fibres were of ICI provenance. They contained 97% Al_2O_3 and 3% SiO_2 and their average diameter and length were 3 μm and up to 150 μm, respectively. The light micrographs illustrating structure of the composite in three main planar sections of the pre-form are shown in Fig. 2. Apparently, structures in section planes XZ and YZ are practically identical. The axes of fibres are preferentially coplanar to XY plane. In the plane XY, the random distribution of fibres is documented.

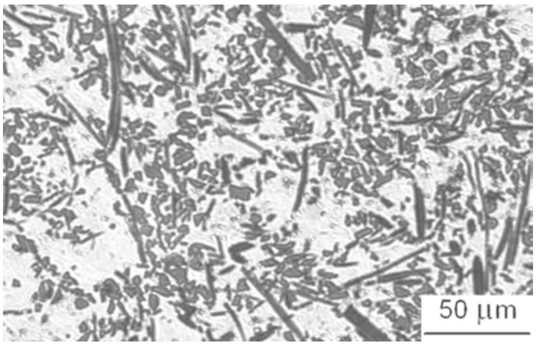


“**Fig. 1.** Scheme of the composite products and procedure of specimen choice.”

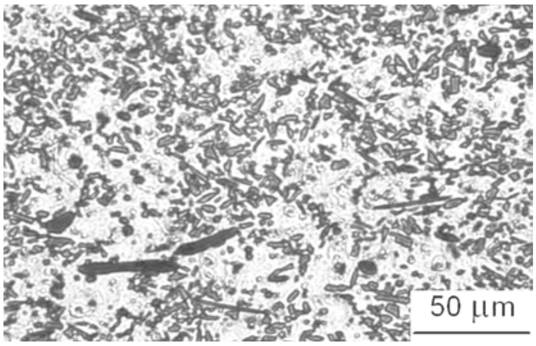


“**Fig. 2.** Structure of the composite AS21_F in three main planes of the pre-form.”

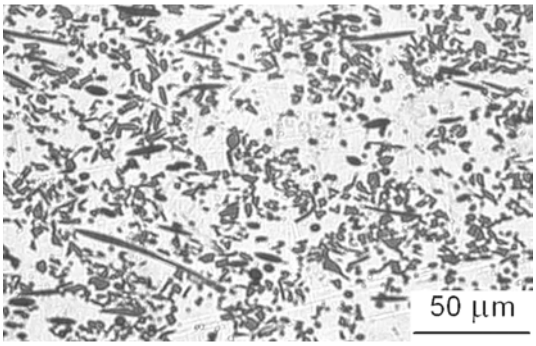
The structure of composite AS21_H in main planes of the pre-form is illustrated in Fig. 3. Qualitatively, the distribution of fibres is similar to the distribution in composite AS21_F-typically preferential planar distribution. The average length of fibres was up to 120 μm and



Plane XY



Plane YZ



Plane XZ

"**Fig. 3.** Structure of the composite AS21_H in three main planes of the pre-form."

their average diameter was approx. 3 μm. Parameters of fibre do not differ significantly from the dimensions of fibres in the composite AS21_F. Added coarse SiC particles are relatively homogeneously distributed. Their size was up to 10 μm.

Cast blocks of both composites were not subjected to a further heat treatment procedure before testing. From the cast blocks, sufficient volumes of the alloy without fibres could be taken for the preparation of experimental specimens for a comparative study of creep behaviour of the matrix alloy. Some results of this study were already published [4].

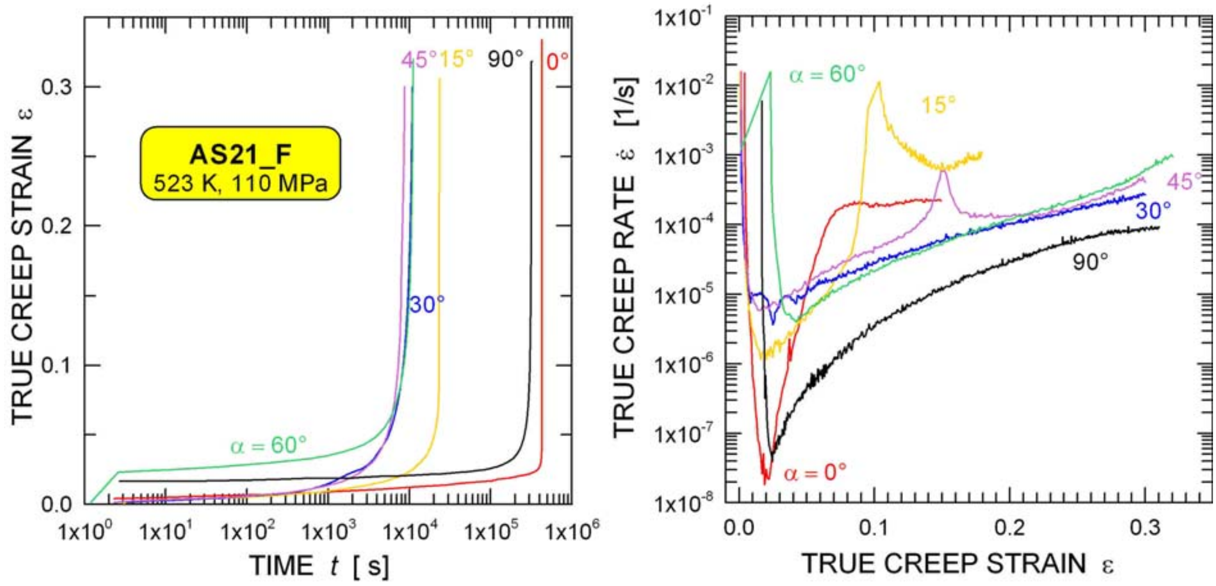
The procedure of specimen choice for the orientation influence on creep behaviour is apparent from Fig. 1. The composite volume of ingots was cut parallel with the plane YZ into parts of 7 mm thickness. Obtained parallelepipeds were spark cut under chosen angles α into semi-products with cross section 7 × 7 mm; then, specimens were manufactured in the final parallelepiped form with dimensions 6 × 6 × 12 mm. The last procedure of specimen surfaces was fine grinding and polishing by diamond paste. This procedure allowed light metallographic revisions of quality of fibre distribution in the specimen. Note, that a pair of opposite sides of each specimen was coplanar with the plane YZ of the pre-forms.

Constant stress compressive creep tests of both composites were performed at temperature 523 K. Special creep machine [5] was used allowing to perform tests in a protective atmosphere of dried and purified argon. A uniform temperature regime was maintained before the start of each test. During the test, temperature was kept constant within 1 deg. Creep curves were PC recorded by means of special software. The sensitivity of strain measurements was better than 10^{-6}.

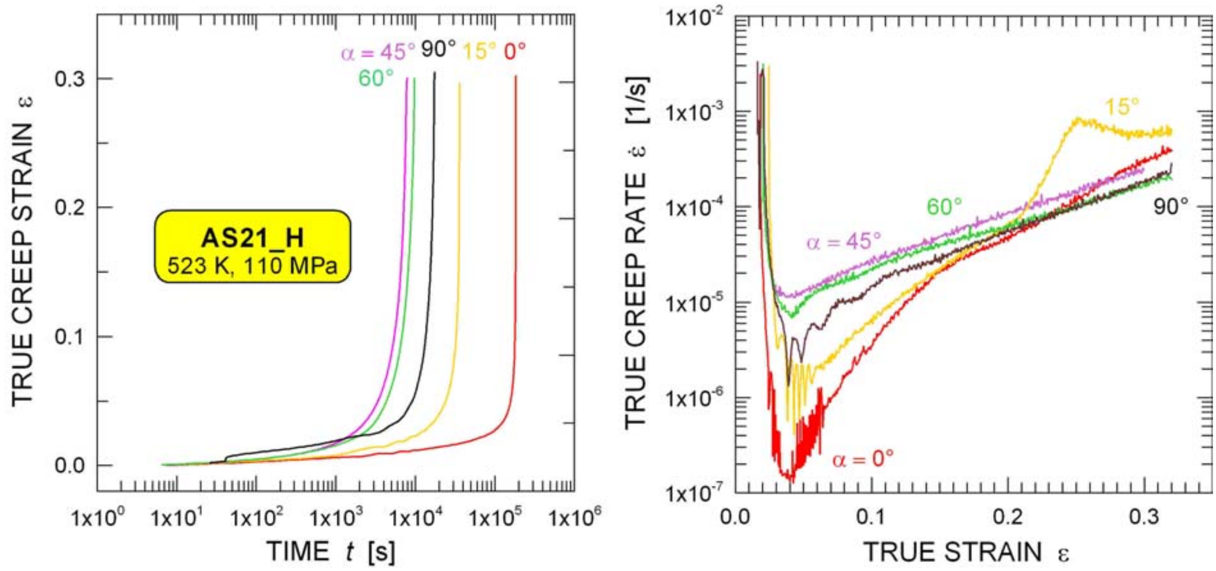
2. RESULTS & DISCUSSION

2.1 Creep curves

Examples of typical compressive creep curves for both composites are plotted in Figs. 4 and 5. Each of the creep curves had usual three stages of creep. The primary stage was very short



“**Fig. 4.** Examples of creep curves of the composite AS21_F.”

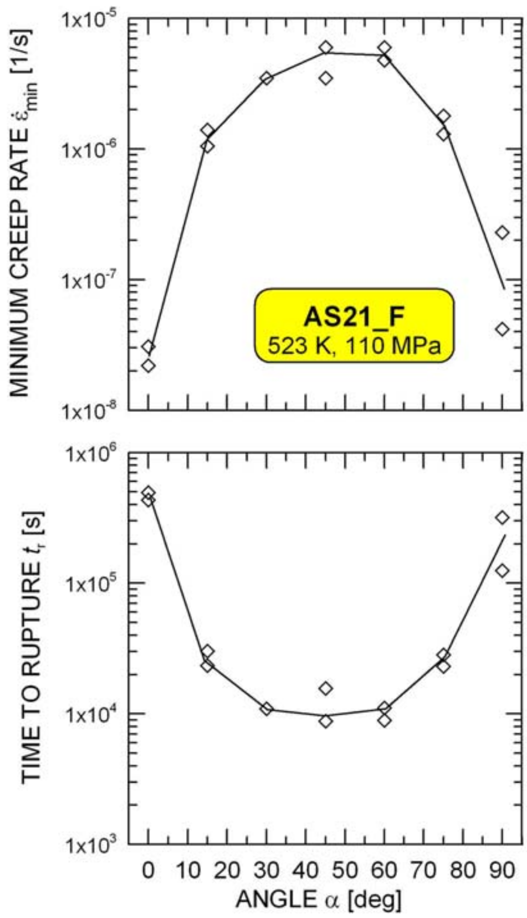


“**Fig. 5.** Examples of creep curves of the composite AS21_H.”

in all tests; it did not overreach level of 5 percent of true creep strain ε. The secondary stage with a very short region of the minimum creep rate $\dot{\varepsilon}_{min}$ was observed on each curve. The relatively long tertiary creep was – as a rule – finished by a destruction of the specimen into several connected macro-blocks (see later). At limiting true strain of the creep used machine ($\varepsilon \approx 0.32$), all specimens could be considered ruptured and corresponding time to rupture could be determined. Irregular progression of the dependence $\dot{\varepsilon}_{min}$ versus ε (local accelerations and consequent retardations) observed in some creep curves - namely in the vicinity of minimum creep rate - are probably due to discontinuous straining processes of the composites. However, these effects necessitate more detailed and complex investigation including detailed observations of corresponding structure development.

2.2. Composite AS21_F

The influence of the specimen orientation on creep parameters, i.e., on the minimum creep rate $\dot{\varepsilon}_{min}$ and time to rupture t_r, was tested in creep tests at temperature T = 523 K and applied stress σ = 110 MPa. Dependences of the minimum creep rate $\dot{\varepsilon}_{min}$ and time to rupture t_r on the angle α are plotted in Fig. 6.

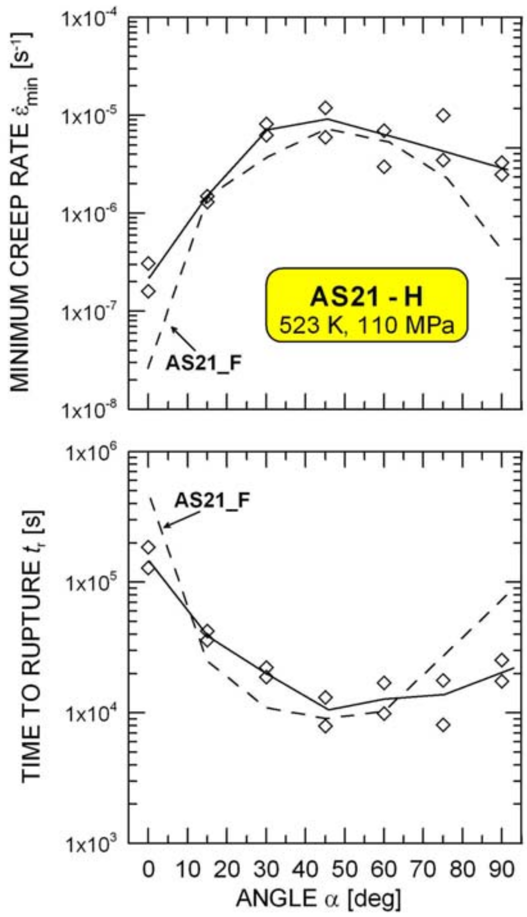


"**Fig. 6.** Orientation dependence of the creep parameters - composite AS21_F."

The strong influence of the angle α on both these parameters is apparent from the figure. A minimum creep strength corresponds to the angle $\alpha = 45°$. At this angle, the rate $\dot{\varepsilon}_{min}$ and the time t_r are approximately 30 times greater or lower, respectively, than for the angle $\alpha = 0°$ under chosen creep conditions. No simple explanation of this effect can be suggested without detailed knowledge of deformation mechanisms controlling creep of the composite. The fact, that the final creep behavior of the composite is determined by a complex of strengthening effects of the matrix alloy with precipitating particles of secondary phases and supplemental reinforcing influence of fibers, must be taken into account. However, the dominant influence of fiber distribution is quite beyond dispute in this composite. The strengthening effect of precipitated particles does not depend on the orientation of the specimen. Influence of the fibre reinforcement on creep characteristics of the composite AS21_F was discussed in detail elsewhere [4].

2.3. Composite AS21_H

Dependences of the rate $\dot{\varepsilon}_{min}$ and time to rupture t_r on the angle α obtained in the composite AS21_H under identical creep conditions, i. e., T = 523 K and stress σ = 110 MPa, are shown in Fig. 7. A strong dependence of both parameters on the angle α has been obtained also in this type of the composite. However, the shapes of the dependences differ from those obtained in the composite AS21_F. While the dependences of both parameters were rather symmetrical with respect to an axis α = 45 ° in the composite AS21_F, these dependences are not so strong in the interval of angles α greater than 45 ° in the hybrid composite AS21_H. Probably, the relatively small fibre content in the composite has a not so great reinforcing influence at these angles. The strengthening effect of coarse particles of SiC can also contribute substantially to the creep resistance of the composite; this effect should be independent of the angle α. However, the strengthening contribution of SiC particles does not fully compensate the lowered content of fibres in the composite AS21_H (compare dashed polylines).



“**Fig. 7.** Orientation dependence of the creep parameters - composite AS21_H.”

For an explanation of possible mechanisms acting in creep, a knowledge of activation parameters of creep resulting from temperature and applied stress dependence of the minimum creep rate $\dot{\varepsilon}_{min}$ and time t_r is necessary. From this point of view, the influence of the orientation on these activation parameters should be also very useful in any consideration. In the present paper, only applied stress dependences of the minimum creep rate $\dot{\varepsilon}_{min}$ and time t_r for various values of the angle α were obtained for the composite AS21_H and both are plotted in Fig. 8. Straight lines can be drawn through the experimental points in the chosen coordinate log-log system. This implies that the applied stress dependences of the rate $\dot{\varepsilon}_{min}$ and time t_r can be well described by a power Norton relation. Therefore, the stress sensitivity

"**Fig. 8.** Stress dependences of the minimum creep rate and time to rupture for various angles α - composite AS21_F."

parameters n and n_r, that are defined as $n = (\delta \ln \dot{\varepsilon}_{min} / \delta \ln \sigma)_T$ and $n_r = -(\delta \ln t_r / \delta \ln \sigma)_T$ do not depend on the applied stress in its experimental interval; both are determined by slope of drawn straight lines. Apparently, the parameters probably do not depend on the angle α with an exception of $\alpha = 45°$. Both parameters reach relatively very high values – approximately 15. None of as yet suggested models of creep in MMC's assumes such high values of the parameter n. On the other hand, the fact that the parameter n and n_r does not probably depend on the angle α could be considered the support of identical mechanism of creep at any α. Similar consideration should support also identical mechanisms of rupture (identical n_r).

Morphology of the ruptured specimens

Nearly identical conclusions concerning the morphology of ruptured specimens were obtained in both composites investigated. The shapes of ruptured specimens of the composite AS21_F with different orientations of the axes are illustrated in Fig. 9. The macro-appearance of all ruptured specimens is very similar at all angles α; there are two typical features of the rupture.

"**Fig. 9.** Shapes of specimens of the composite AS21_F with various angles α."

First, it can be seen that the rupture process does not probably proceed along the planes of fiber distribution but most probably along the planes of maximum shear stress in this type of the creep test. Apparently, massive slip of specimens parts has occurred predominantly along these or parallel planes. Second, all these "slip planes" are perpendicular to one of the opposite pairs of sides of the specimen parallelepiped (front sides of the specimens in Fig. 9). Naturally, there is a question, how these "slip planes" are oriented to the main planes of the composite (Fig. 1). A detailed metallographic observation has shown that all these planes are parallel or quasi-parallel with the coordinate X or Y. It means that rupture slip must go across the planar fibre distribution in all ruptured specimen. An exception is the angle α = 45 °. In this case, there is a parallelism of the planes of fibre distribution and maximum shear stress in the specimen.

3. CONCLUSIONS

The investigations of the influence of orientation between the acting stress and quasi-planar distribution of reinforcing fibres in the investigated composites have shown:

- There is a strong dependence of the creep resistance on the angle α of axis orientation in both materials;
- Maximum creep resistance is observed if the stress acts parallel with the planes of fibre distribution ($\alpha = 0°$);
- Minimum creep resistance corresponds to the angle $\alpha = 45°$ in both investigated composites;
- Creep resistance of the composite with fibres only at $\alpha = 90°$ is slightly lower than that at $\alpha = 0°$;
- Creep resistance of the composite with hybrid pre-form is rather constant at angles $\alpha > 45°$;
- Stress sensitivity parameters n and n_r of the minimum creep rate and time to rupture, respectively, do not probably depend on the orientation of the applied stress axis and planes of fibre distribution;
- Creep rupture of specimens expands across planes of distributed fibres at all angles α.

ACKNOWLEDGEMENTS

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