FAILURE OF Al_3Ni+Al COMPOSITES AT ROOM AND HIGH TEMPERATURES

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INTRODUCTION

Mechanical properties of particle composites depend on various factors (particle size, shape, and volume fraction, particle and matrix stability in respect to phase transformations etc.), important among these factors is the interaction between particle and matrix, the properties of particle-matrix interface. As far as we are interested in the failure as limiting factor of mechanical properties of composite material, there are two possibilities, *viz*. one of interfaces is a "weak" link, or the failure starts either in matrix or in second phase(s).

The aim of this study is to examine mechanical properties and verify the failure mechanism of the composite prepared by diffusion of Ni into Al and consisting of Al_3Ni particles in Al matrix. The composite was tested at room and high temperatures.

KEYWORDS

In-situ composites, mechanical properties, failure mechanism.

MATERIAL AND EXPERIMENTS

The composite Al_3Ni+Al was prepared by plasma spraying of nickel (some experiments were performed with Ni20Cr) on Al sheet (5N purity), followed by annealing at temperature just below of melting temperature of Al_3Ni+Al eutectics, i.e., 640 °C. Al_3Ni phase is orthorombic (oP16) with lattice parameters a = 6.61, b = 7.37, and c = 4.81 Å (for comparison: FCC aluminium lattice parameter is a = 4.05 Å). Eutectic concentration of Ni is 2.7 at.% and volume fraction (calculated) of Al_3Ni particles in eutectics mixture is approximately 9.7 %. The isolated metastable monoclinic Al_9Ni_2 phase, see, e.g. [1], was occasionally found. Details of specimen preparation, structures obtained by annealing at temperatures between 450 and 635 °C, and composite's properties could be found elsewhere, [2, 3].

The structure of materials obtained was studied by means of light microscopy, image analysis, SEM, EDS. TEM was attempted, but results are not complete due to problems with specimen preparation.

Two sets of composites were prepared for mechanical properties measurement. First by annealing at temperature 625 °C for 8, 16 and 30 hours. Second set by annealing at 635 °C for 1.5, 1.75 and 2 hours. Structures obtained by diffusion of Ni into Al substrate could be briefly described as:

- Depending on time and temperature interlayer of various thickness and composition forms while thickness of Ni coating remains constant (transfer of Ni atoms into the substrate leads to the cavities formation in the coating). The interlayer between coating and substrate is formed mainly by alloy of Al_3Ni composition and very fine-grained (nanocrystalline) structure. Depending on conditions, this interlayer may exhibit concentrations of Ni corresponding to other phases (Al_9Ni_2 on Al rich, substrate, side, Al_3Ni_2 on Ni rich, coating, side) or the concentration profile may be irregular.
- At temperatures higher than approximately 600 °C, Ni moves futher in the substrate and band consisting of Al_3Ni particles in Al matrix forms. This band, when fully developed, has a eutectics concentration of Ni and eutectics volume fraction of Al_3Ni particles. Particles are plate-like. At the short times (lower temperature) particles volume fraction is less than that corresponding to the eutectics, when diffusion front "sweeps" whole specimen's width, volume fraction of particles increases above eutectics and particles coarsen. Ni content in Al_3Ni particles varies across the particle, usually the exact stoichiometric concentration is attained in the centre of the particle only. Coarse particles achieve stoichiometry by reverse dissolution of particles' centre, thus large particles contain Al isles in their middle.

Figure 1 shows the growth of interlayer and band of eutectics Al+Al_3Ni at 630 °C (image analysis results), i.e. at temperature where both features fully develop.

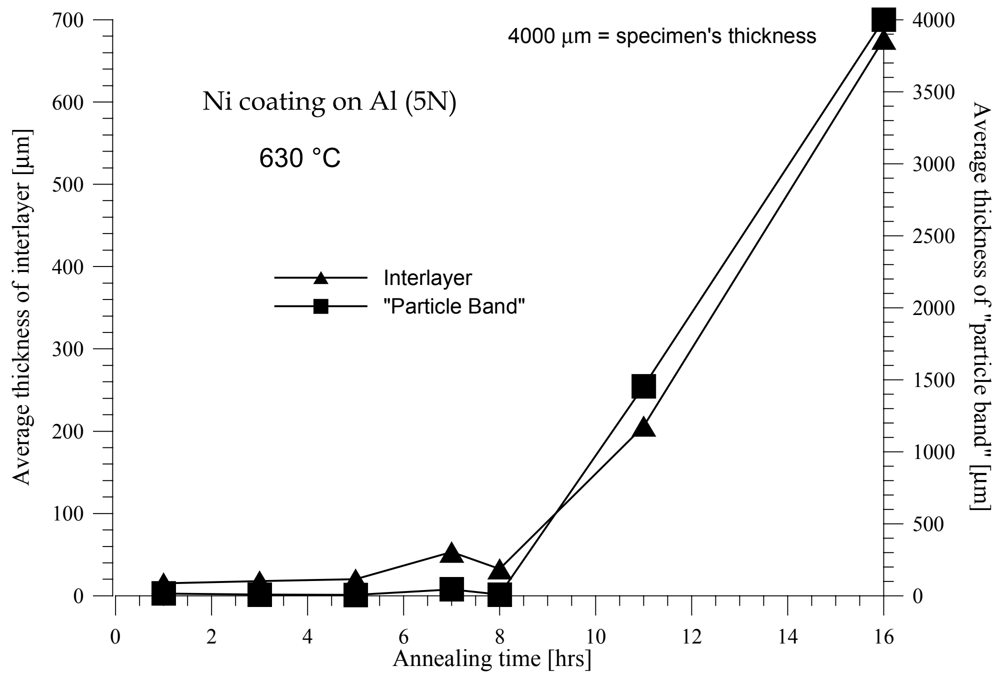

Fig. 1 Growth of interlayer (nanocrystalline band adjacent to the coating, composition approximately Al_3Ni) and Particle band (composite structure formed by Al matrix and Al_3Ni particles - composition of eutectics until the diffusion front reaches opposite side of specimen).

RESULTS OF MECHANICAL TESTING

Following Table 1 summarises structural elements and corresponding room temperature mechanical properties. For comparison it also contains results obtained on pure Al after the same HT. An example of creep properties is in Fig 2. RT tensile tests show how strength characteristics improve in composites but at the expanse of plastic properties. Creep testing proved superior properties of composites over pure Al (and some common Al alloys) at low stress values. At high loads difference between two types of materials diminishes. Although Fig.2 contains for clarity only the results for one composite (625 °C/16 hrs), other composites displayed similar relations.

Tab.1 Composites and tensile tests results

HT/ Material	Particle Band Thickness [μm]	Al_3Ni Particle Size [μm]	Volume Fraction of Particles [%]	$R_{p0.2}$ [MPa]	R_m [MPa]	Elongation [%]
625°C/8 hrs						
Al				8.6	55.2	36.6
Composite	202	13	1.3	42.7	68.6	20.6
625°C/16 hrs						
Al				8.8	51.3	36.9
Composite	196	21	1.4	47.4	68.6	22.7
625°C/30 hrs						
Composite	433	25	1.5	47.4	69.1	14.2
635°C/1.5 h						
Composite	345	29	11	83.8	86.7	2.61
635°C/1.75 h						
Al				9.0	54.6	26.8
Composite	4000	35	13	91.5	152.7	0.37
635°C/2 hrs						
Composite	4000	182	36.5	154.8	155.4	0.49

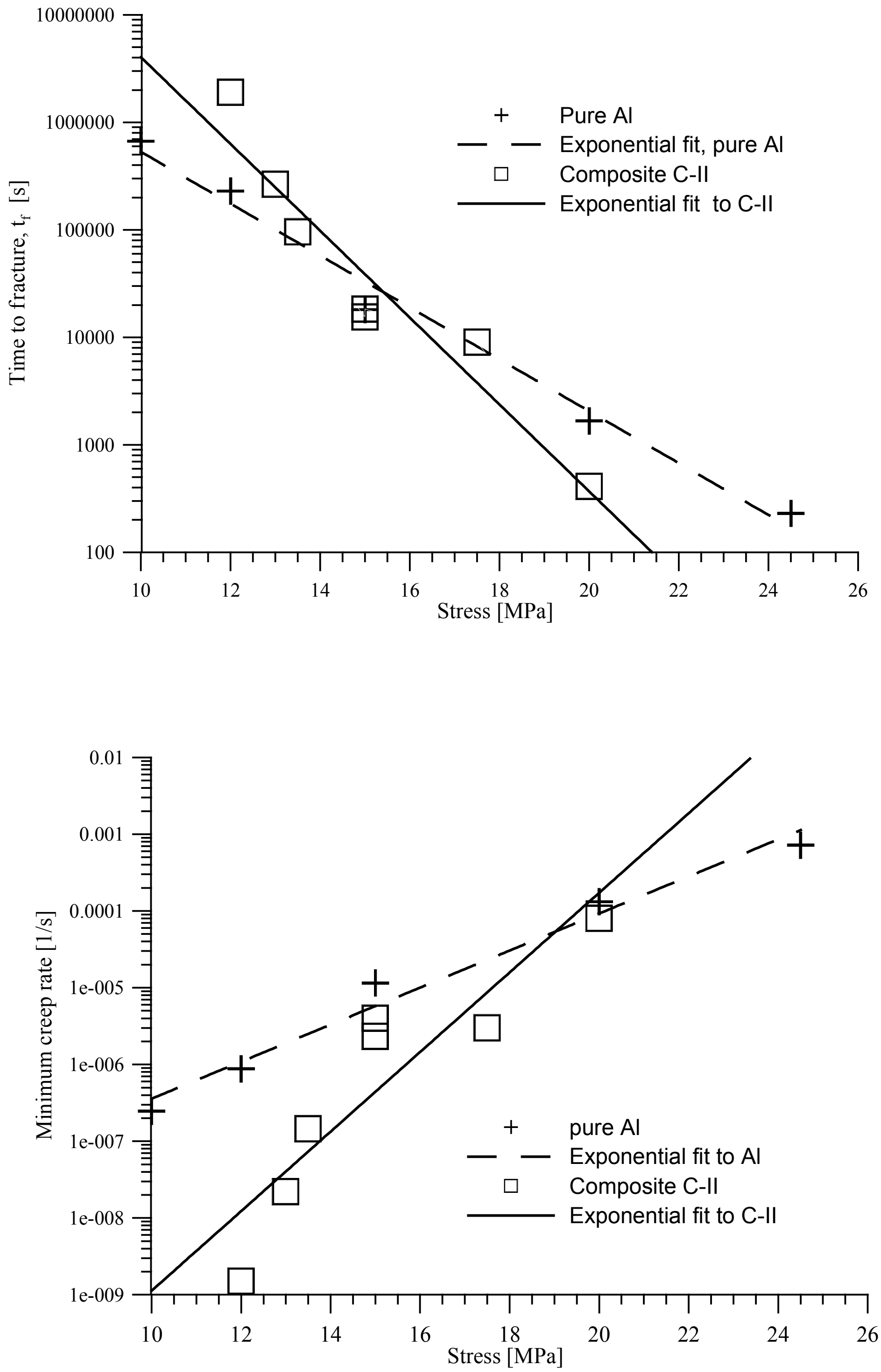

Fig. 2 Time to fracture (top) and minimum creep rate (bottom) dependence on applied stress for pure Al and composite C-II (625 °C/16 hrs).

FRACTOGRAPHY

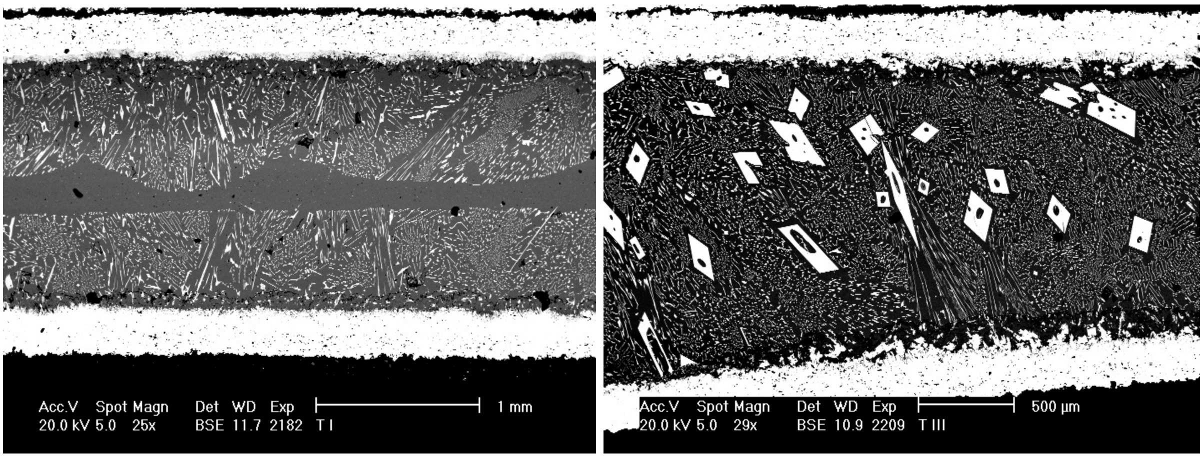

Fig. 3 Cross section of specimens used for mechanical properties measurements. 635 °C/1.5 hour (left) and 635 °C/2 hrs (right). White bands on the top and bottom of specimens are coatings, with adjacent thin grey bands of interlayers.

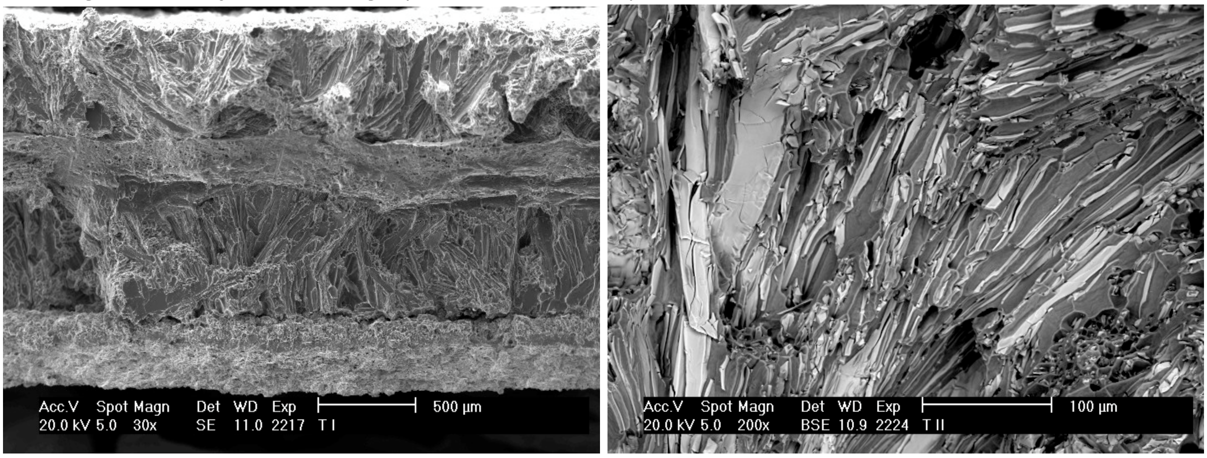

Fig. 4 At left: Composite with Al band in the centre (635 °C/1.5 h). Various layers are distinguishable, from bottom: coating, interlayer, Al_3Ni+Al eutectics, pure Al, Al_3Ni+Al eutectics, interlayer. At right: composite with eutectics in whole volume (635 °C/1.75 h).

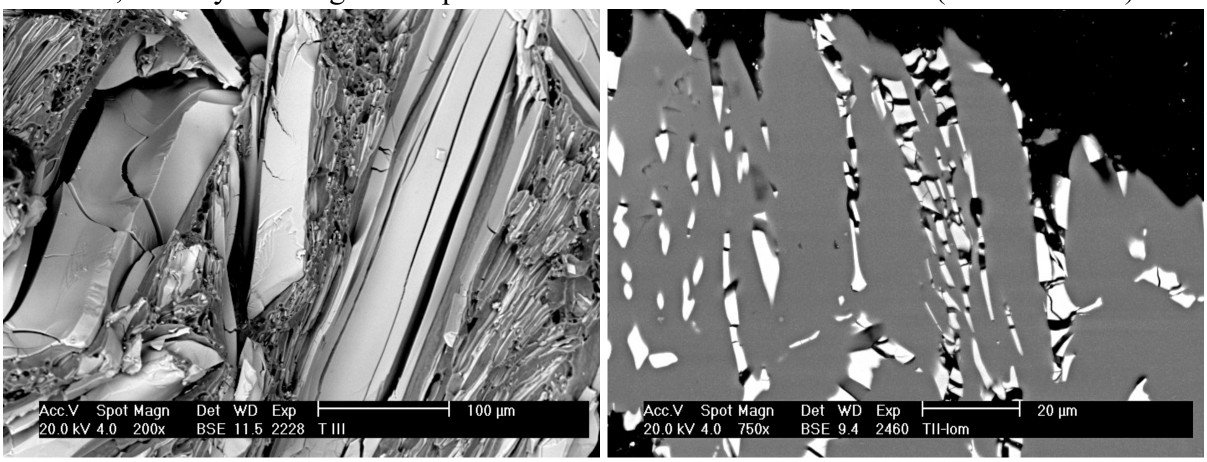

Fig.5 Composite with coarse Al_3Ni particles (635 °C/2 hrs). Fracture surface (left) and section perpendicular to the fracture surface (right).

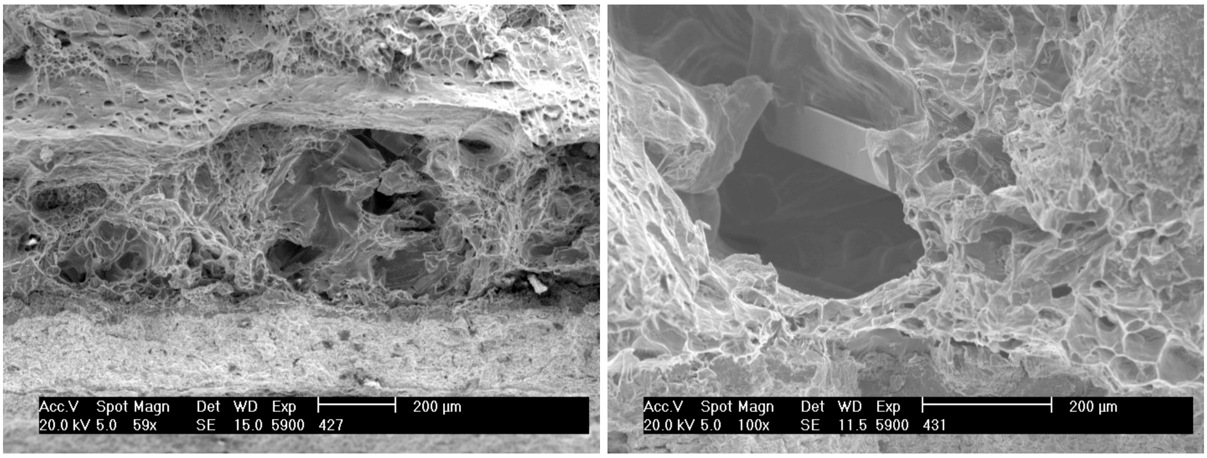

Fig.6 Creep tested specimens (400 °C). At left: composite 630 °C/5 hrs. From bottom: coating, interlayer, eutectics, pure Al. At right: composite 630 °C/10 hrs. Detail of fractured Al_3Ni particle.

DISCUSSION AND CONCLUDING REMARKS

Limited TEM analysis showed that electron diffraction from Al_3Ni do not usually correspond to ideal Al_3Ni, simulations by CaRine Crystallography 3.1 suggest that some Ni atoms are substituted by atoms of aluminium or the LRO order is disturbed, or both. On the other hand, the plate-like shape of precipitates demonstrates the orientation relationship between crystal lattices of matrix and Al_3Ni phase.

The performance of particle reinforced composites is most often controlled by the properties of the particle-matrix interface. In our case, the particle-matrix interface certainly do not represent "weak link". The reason is, partially, small "misfit" between different sets of crystallografic planes. For example the difference of planar spacing between $\{100\}_{Al}$ and $\{011\}_{Al3Ni}$ is less than 0.5%, between $(310\}_{Al}$ and $\{313\}_{Al3Ni}$ less than 0.2%, etc.

SEM micrographs of fracture surfaces and cross sections of failed specimens prove that most frequent cause of the fracture of material is cracking of Al_3Ni particles. Fig. 4 shows fracture surfaces of most complicated case, i.e., specimen with "sandwich" structure consisting of layers with very different properties. There are not large "steps" between different strcutres. Fracture surface is following approximately one plane. It could be clearly seen, Fig. 5, that even particles cracked at several places, their pieces moving separately in the matrix, remain securely bonded to aluminium. This is even true at high temperature creep tests, Fig. 6.

We can deduce that Al_3Ni particles are prone to crack under triaxial stress which arises in the specimen after some deformation of plastic Al matrix. To improve further properties of strengthening phase, few means offers themselves. It is possible to modify size and shape of the particles by refining heat treatment. Also composition of particles and matrix may be adjusted. Some experiments were performed on Al of commercial purity and Al_3Fe particles (Fe and Si being most common impurities in commercial Al sheets) exhibited high Ni content even at large distances before diffusion front.

The interest focuses recently on Al-Ni alloys with high Al content, e.g. [4, 5]. Applications are till now more in the field of abrasion resistant [6] than structural materials. Nevertheless interesting properties and wide possibilities of their modification, certainly justify further research.

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