

Synthesis of quasicrystal/polymer composites

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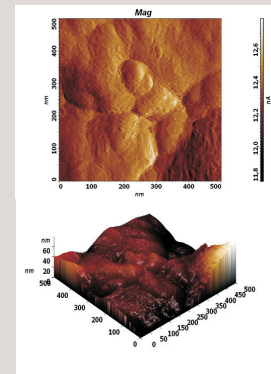
Introduction

Ultrahigh molecular weight polyethylene (UHMWPE) is used in orthopaedic implants due to outstanding wear properties. In spite of the low wear behaviour of UHMWPE compared to other polymers, wear remains a major problem in total joint replacements. Submicron wear particles cause foreign body response leading to bone resorption (osteolysis) and loosening of implant components. This further limits the life expectancy of hip prostheses [1-2]. Therefore, improving the wear resistance of UHMWPE can substantially extend the clinical life span of total hip prostheses. It was recently reported that quasicrystalline fillers may significantly improve wear resistance in polymer-based composites [3-4].

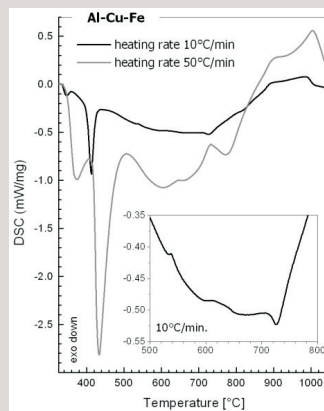
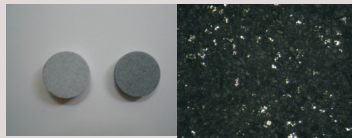
Since the discovery of icosahedral phases in rapidly-quenched Al-Mn alloys [5], quasicrystals (QCs) were observed in over 100 alloy systems. Among them, the ternary Al-Cu-Fe alloy is most interesting [6-9], thanks to excellent properties, such as the low electrical and thermal conductivity, high hardness, low friction and wear, and good oxidation resistance.

Nanopowder Synthesis & Characterization

Polymer composites of Al-Cu-Fe quasicrystal and polyethylene were prepared. Polyethylene was purchased from Aldrich and used as received. Nanocrystalline Al-Cu-Fe powders were prepared by mechanical alloying (MA), using a PM 400 (RETSCH, DLR) planetary ball-mill. Wet-milling in hexane was employed to counteract severe powder losses during MA, avoid sever contamination from grinding media and prevent oxidation effects. No other milling additives were used. High purity powders of Al (99.95%), Cu (99.95%) and Fe (99.95%) were loaded in hardened chromium-steel vials together with 10 and 20 mm steel balls. The ball-to-powder ratio (BPR) was chosen equal to 14:1. The milling time was 25 h at room temperature.

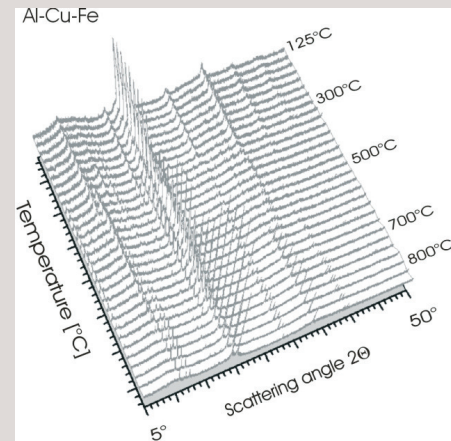


Mixtures of polyethylene (60 volume percent) and Al-Cu-Fe powders (40 volume percent) were weighed, added together with a solvent and mixed for 1h to provide optimum mixing. The resulting Al-Cu-Fe/UHMWPE mixture was dried at room temperature, then shaped into disk pellets (Ø 20 mm) by uniaxial pressing at 200 kN. Composite Al/polyethylene specimens were prepared in a similar way using Al (99.95%) powder.



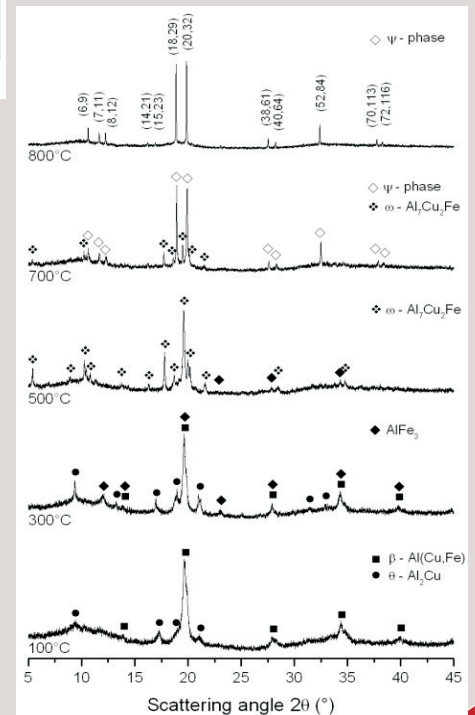
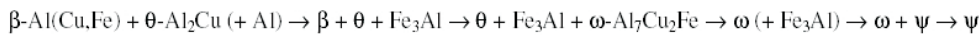
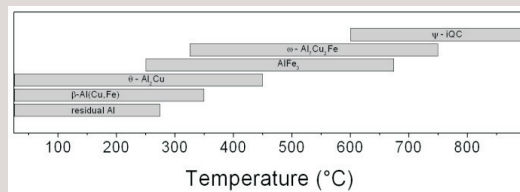
The formation of QCs during non-isothermal annealing of the Al-Cu-Fe nanopowders was studied by differential scanning calorimetry (NETZSCH Pegasus 404C). The DSC traces obtained during heating at 10 and 50°C/min. show two well-defined exothermic events in the low temperature range below 500°C, presumably related to the formation of AlFe₃ and Al₇Cu₂Fe phases. A more complex sequence of thermal events is observed above 500°C. The increase of the heating rate causes a moderate positive shift (approx. 20°C) of the phase transition temperatures, otherwise the sequence of thermal events does not change.

Synchrotron Radiation X-ray Diffraction



The *in-situ* synchrotron radiation diffraction experiments were performed at the high-resolution B2 powder diffractometer in HASYLAB -DESY in Hamburg (Germany). The powder specimens were sealed inside quartz capillaries mounted on a rotating sample holder inside a furnace operated under continuous Argon flow. Constant rate heating and isothermal experiments were performed at various temperatures up to 900°C. The scattered intensity was recorded using an image-plate detector which allows for the one-step acquisition of wide-angle diffraction patterns within few minutes.

The time-resolved energy-dispersive X-ray diffraction experiments were performed at the MAX80 multiple-anvil high-pressure station (beamline F2.1) in HASYLAB.



Conclusions

quasicrystal/UHMWPE composites with a highly uniform dispersion of AlCuFe QC particles in the polyethylene matrix can readily be achieved by wet-mixing. The resulting composite powders may further be shaped into bulk solid bodies by pressing or extrusion.

Prospects

research is underway to investigate properties of the composites, like biocompatibility, mechanical response, as well as the wear and oxidation resistance.

Glossary

Quasicrystals - a class of aperiodic long-range-ordered solids.
MA (mechanical alloying) - a solid-state powder processing technique involving repeated welding, fracturing and rewelding of powder particles in a high-energy ball mill
DSC (differential scanning calorimetry) - a thermoanalytical technique in which the difference in the amount of heat required to increase the temperature of a sample and reference are measured as a function of temperature
XRD (X-ray diffraction) - a technique used to characterize the crystallographic structure, crystallite size (grain size), and preferred orientation in polycrystalline or powdered solid samples
Synchrotron Radiation - when charged particles, in particular electrons or positrons, are forced to move in a circular orbit, photons are emitted. At relativistic velocities (when the particles are moving at close to the speed of light) these photons are emitted in a narrow cone in the forward direction, at a tangent to the orbit. In a high energy electron or positron storage ring these photons are emitted with energies ranging from infra-red to energetic (short wavelength) X-rays. This radiation is called Synchrotron Radiation.

References

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