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Zentallium® - the Al-CNT nano-composite for high-performance light weight applications

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***Abstract*— Mechanical alloying of aluminum (Al) with multi-walled carbon nano tubes (CNT) by high kinetic processing (HKP) yields a novel Al-CNT nano composite, Zentallium® Z21, which provides mechanical properties similar to state-of-the-art aluminum lithium (Al-Li) alloys used in light weight construction. Zentallium® Z21 shows great promise to be the next generation of light weight materials with high mechanical performance requirements because beside other favorable properties it is lighter than titanium and strong as steel.**

Keywords – Zentallium®; aluminum-CNT composite; mechanical alloying; Simoloyer®; high kinetic processing

I. Introduction

Within the last years the research interest in carbon nanotube (CNT)-reinforced aluminum has grown considerably with the major aim to enhance mechanical properties with respect to pure aluminum. CNTs are excellent nano scale reinforcements as they exhibit low density (1.3 g/cm^3), high elastic modulus (about 1 TPa) as well as high tensile strength up to 150 GPa. Thus a composite material should have lower density than the original metal with improved mechanical properties. At the same time, aluminum alloys are used for light weight construction, i.e. the aluminum-lithium alloy Al-Li 8090 in aerospace engineering. Unfortunately, conventional alloying is not possible as CNTs degrade in aluminum melt. Instead, mechanical alloying (MA) is the route to Al-CNT composites.

The majority of research concerning MA to obtain Al-CNT composites is based upon planetary ball milling of the components, which is sufficient for laboratory scale experiments. Yet, planetary ball milling faces the problems that typically a process control agent, i.e. methanol or heptane, is necessary and CNTs tend to aggregate [1-2], which makes it difficult to obtain a good dispersion of CNTs in the metal matrix.

In this contribution it will be shown that when using the Simoloyer® horizontal rotary high energy ball mill, dry milling is applied, which means the liquid organic process control agent can be avoided, and an excellent homogeneous dispersion of CNTs is achieved. The reason is intrinsic to high kinetic processing (HKP) as implemented in Simoloyer® technology (see section II). This yields the Al-CNT composite Zentallium® Z21, a top performance material for light weight construction.

II. High Kinetic Processing

The design of the Simoloyer® is based on a horizontally borne rotor, which allows a highly efficient and homogeneous energy transfer from the supplied power to the kinetic energy of the balls (grinding media), which are accelerated by the rotor. This yields collisions between the balls with maximum relative velocities up to 14 m/s. In the high kinetic regime, these collisions transfer energy to the powder mainly as pressure, with only minor contributions of shear and friction. As a result, powder particles are deformed, broken, recombined by cold welding up to alloying at the nanoscale, and/or a combination of all is possible. Compared to vertical conventional attritors the horizontal design avoids dead zones of interaction between grinding media and powder. Furthermore, a well-defined atmosphere can be maintained throughout the milling process, i.e. inert gas atmosphere which is necessary for the processing of Al-CNT-composites. This allows highly efficient MA with processing times up to 1000x faster than with conventional mills. As most of the collisional energy is converted into pressure and very little energy is lost to shear and friction, the overall amount of energy to be supplied to the grinding media is below conventional milling as well. This is both economically and ecologically highly effective.

The special design of the Simoloyer® allows full scalability from laboratory size (0.5 l) to full industrial scale (900 l) without changing the principle milling system [3-4]. A laboratory scale 2 l Simoloyer® is shown in Fig. 1.

Fig. 1. Simoloyer® CM01-2lm high energy rotary ball mill and transparent grinding unit (front)

III. Results and Discussion

MA of an Al 5083 aluminum alloy and CNTs by HKP yields Zentallium® Z21, an Al-CNT nano composite with tensile strength comparable to the Al-Li 8090 alloy used in aerospace engineering. It exhibits excellent dispersion of multi-walled CNTs in the aluminum matrix. Similar to Al-CNT nano composites known from laboratory research, the powder obtained after HKP was hot extruded (cf. Fig. 2) before testing. The entire process was dry, hence neither methanol nor any other organic solvent was needed as process control agent. Furthermore, HKP as performed here provides an effective use of supplied energy, hence saving energy, a direct result of the intrinsic features of Simoloyer® technology (see section II for details). Primarily, the direct and efficient transfer of energy from the balls to the powder is responsible for a fast and energy-efficient milling process effectively inserting CNTs into the metal matrix at minimal energy consumption.

Fig. 2. Hot extrusion of Zentallium® Z21 to semi-finished products (*here: rods*).

Compared to the original aluminum alloy without CNTs, tensile strength of Zentallium® Z21 doubled, whereas the density slightly decreases and the elastic modulus increases by 14%. The tensile strength is similar to the aerospace engineering alloy Al-Li 8090. In comparison, stainless steel has the same tensile strength, around three times higher elastic modulus, but at the expense of three times higher density. Hence, whereas steel is no light weight material, Zentallium® Z21 is a light weight material competitive to conventional alloys for demanding light weight applications. It should also be noted that activity based costs for Zentallium® Z21 production are significantly below those for conventional alloying.

For future improvement recent insight can be applied which states that an increase of CNT diameter yields increases tensile strength of Al-CNT composites [5]. Here may be some potential for the optimization of Zentallium®, which may bring it into closer proximity to titanium alloy performance.

IV. Conclusion

HKP has been successfully applied to MA of an Al alloy with CNTs. The resulting Al-CNT nano composite material, Zentallium® Z21, can sustain the same tensile stress as stainless steel, with the low density of an aluminum alloy. The intrinsic features of HKP with the Simoloyer® horizontal high energy ball mill yield well-dispersed CNTs in the metal matrix from a dry, energy-efficient milling process, hence getting rid of organic solvents and saving energy. Further optimization by changing the site or amount of CNTs is possible, which may either yield even higher strength at the same density of the material, or allows custom solutions to specific material requirements. Due to fast milling times, large amounts can be produced with industrial scale Simoloyer® mills if necessary and at significantly lower cost than conventional high-performance aluminum alloys. This makes Zentallium® a hot candidate for next-generation light weight materials.

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