APMA-2017
The 4th International Conference on Powder Metallurgy in Asia
Apr. 09-11, 2017, Hsinchu, Taiwan

Nanostructured Ferritic Alloys (NFA) as the next gen. ODS manufactured by high kinetic processing (HKP)

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Abstract— **Oxide dispersion strengthened alloys and nanostructured ferritic alloys are promising candidates for high temperature applications such as fission and fusion power plants because of their structure and resulting properties. There is a novel approach for processing such alloys utilizing mechanical alloying by Simoloyer® high energy ball mills leading to a new generation of nanostructured ferritic alloys. These alloys are suitable for new powder metallurgical consolidation methods.**

Keywords – oxide dispersion strengthened alloys; nanostructured ferritic alloys; Simoloyer®; high kinetic processing; mechanical alloying

I. Introduction

Development and improvement of materials for aerospace, automotive and power generation is an issue of great interest. As far as the demands to materials for high temperature applications have increased during the last years novel oxide dispersion strengthened (ODS) materials, especially based on aluminum-, iron- and nickel-alloys, had to be developed. Already established new and also improved consolidation techniques such as additive layer manufacturing (ALM) including selective laser and electric beam melting (SLM, EBM) or another technique as the metal injection molding (MIM) formulate the needs for the materials properties.

Hence the structural properties like creep and tensile strength at high temperature are as important as the resistance against irradiation damage or corrosion. [2] There are also needs to develop novel cost-effective scalable processing routes in order to reach a wide range of exploitation in all steps of processing. Conventional routes of manufacturing are ineffective due to uncontrolled conditions during the milling step (cf. Fig. 1).

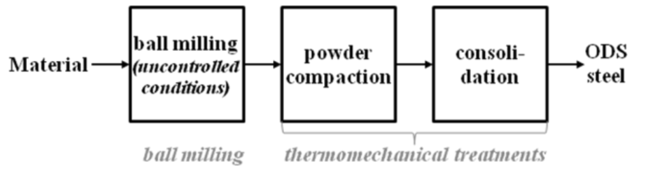

Fig. 1. Process chart for conventional manufacturing of ODS steel

II. ODS- Alloys

Oxide dispersion strengthened alloys have been investigated for a long time, e.g. [3,4] Currently the properties of ODS have to be tailored for special applications.

Already manufactured ODS alloys (e.g. FeCrAl) show an increase of strength of about 40 MPa at 20°C, which means 5-10%, and 70 MPa at 1000°C, which are 400%. Dispersion hardening is the main reason for this impressive strength increase. Solubility is enforced resulting in a homogeneous dispersion of nano-scale precipitations. The expected Orowan mechanism explains the increase of strength (cf. Fig. 2). [5]

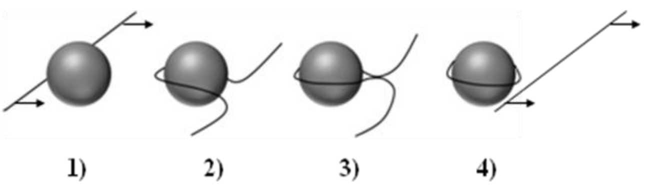

Fig. 2. Orowan mechanism: 1) dislocation and obstacle, 2) dislocation bows around obstacle, 3) attraction of the dislocation at either end of obstacle, 4) dislocation loop around obstacle

Hence the increase of the dislocation line length and the resulting formation of loops around obstacles in form of non-shearable particles driven by shear stress is responsible for increased strength. The dislocation maintains in the same shape after passing by the particles.

III. Nanostructured Ferritic Alloys

A new generation of nanostructured ferritic alloys (NFA) has been developed by dense dispersion of oxides with particle sizes below 10 nm by an innovative process [1]. As dispersoid Yttrium Oxide (Y_2O_3) is added to the raw powder metal alloy for generating ODS-alloys. In comparison to conventional ODS-alloys (10-60 nm), NFAs typically show a finer oxide-nanostructure (<10 nm) independent from grain sizes or boundaries from the initial particles. resulting in improved mechanical properties.

IV. Mechanical Alloying

Analyzing methods and structural investigation of powder alloys and consolidated products have improved as well which also contributes to an advancement of the processing routes. [6]

To achieve the aforementioned forced solubility the application high kinetic processing (HKP), especially of mechanical alloying (MA) by the Simoloyer® is highly recommended. [7] It is a certain processing device in order to provide a suitable transfer of high kinetic energy into the powder material and in order to establish an applicable mode of charging and discharging with clean and inert atmosphere at low contamination during charging, processing and discharging at quantitative yield (Fig 3).

Fig. 3. Simoloyer® CM20-20lm high energy ball mill

This technique can be scaled-up from laboratory (0.5 – 2 liters process volume) to industrial scale (900 liters process volume). Semi-industrial conditions for hundreds of kilos product are established since 2014. [6] Using such advanced process technology leads to full incorporation of the dispersoid into the metal matrix and creates a homogenous network dispersion after subsequent consolidation.

V. Conclusion

Novel nanostructured ferritic alloys with improved properties compared to conventional oxide dispersion strengthened alloys have been manufactured by mechanical alloying with application of the Simoloyer® technology. The synthesized NFAs show incredible high strengths and high resistance against irradiation and high temperature. This has been proven and already established a day-to-day business. This opens a wide range of applications according to the fields of fission and fusion power generation as well as in the field of aviation and transport, everywhere, where materials face radiation, high temperature and high stress issues.

Acknowledgment

Our previous and current cooperation partners, Dr. Richard DiDomizio, Dr. David T. Hoelzer, Prof. Dr. G. Robert Odette, Dr. Stuart A. Maloy and Rainer Lindau are acknowledged for their support and valuable discussions.

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