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Two-step yielding in novel CoNi nanoplatelet-based magnetic fluids under oscillatory rheology

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ABSTRACT

The Core–shell CoNi hexagonal platelet-shaped nanocomposites with average diameter of 202 nm were synthesized by Cetyl-trimethylammoniumbromide (CTAB)-mediated hydrothermal reduction in aqueous precursor. The oscillatory rheology was employed to study the magnetomechanical response of magnetic fluids containing high aspect ratio CoNi nanoplatelets with particular emphasis to viscoelasticity and yielding properties. An interesting two-step yielding behavior in amplitude sweep test was observed for all the magnetic fluids with concentration in the range of 5–12 vol%. This was interpreted in terms of breaking of magnetically induced-microstructure aggregates below and above the cross-over strain. The strain-hardening of loss modulus above the flow point was more prominent in higher concentrated fluids owing to dominance of short-range interaction.

1. Introduction

The CoNi binary alloy is an important member of transition metal alloys due to its diverse potential applications in various fields ranging from magneto-optics to ferrofluids and magnetorheological (MR) suspensions [1–4]. The diverse application ranges of CoNi-based nanostructures originate in their incredible magnetic and catalytic properties, in addition to their enhanced mechanical properties compared to cobalt (Co) and nickel (Ni). Furthermore, CoNi nanoparticles can be synthesized by various wet chemical reduction methods with great ease and accordingly, magnetic and surface properties can also be tuned. In addition to single domain nanoparticles, a wide range of structurally and magnetically anisotropic microstructures of CoNi alloy system can be synthesized by polyol and hydrothermal reduction methods [5].

Magnetic fluids containing anisotropic nanostructures provide excellent control of magnetomechanical properties when employed in magnetorheological (MR) devices. By replacing spherical particles with anisometric materials in MR fluidic systems, MR effect and sedimentation stability can be greatly improved [6]. In this paper, we describe novel oscillatory magnetorheological properties of magnetic suspensions containing CoNi hexagonal nanoplatelets. The CoNi hexagonal plates are of core–shell type with Co concentrated at the core. The oscillatory rheological studies under different magnetic fields revealed a two-step yielding behavior for the fluids with different nanoplate concentrations and broadening of linear viscoelastic regime for lower concentrated fluids.

2. Materials and methods

CoNi plate-like nanoparticles were synthesized by hydrazine-mediated hydrothermal method. For the synthesis, hydrazine was used as reducing agent for the reduction of precursor solution containing Co (II) acetate and Ni (II) acetate ((Aldrich, $\geq$98%)) in equimolar ratio. CTAB (Cetyl-trimethylammoniumbromide, 99%, Loba Chemie) was used as surfactant for directive growth of plate-like hexagonal nanoparticles along the preferred plane. Co (III) acetate (0.05 M), Ni (II) acetate (0.05 M) and CTAB (0.15 M) were dissolved to Millipore® water (30 mL) following stirring using a magnetic stirrer. An aqueous solution of hydrazine hydrate (0.2 M, Ranbaxy™) was added to the precursor dropwise prior to transfer the resulting solution into a Teflon-lined stainless steel autoclave. The autoclave was kept for 21 h inside a hot-air oven set to 160 °C. The supernatant was removed by centrifugation, and the precipitate was vacuum-dried to yield the black powder. For magnetorheological studies under oscillatory mode, three different MR suspensions (namely M1, M2, M3) containing 5 vol%, 8 vol% and 12 vol% of CoNi nanoplatelets were prepared. The appropriate amounts of CoNi powder were dispersed into castor oil following mechanical stirring and ultrasoncation.

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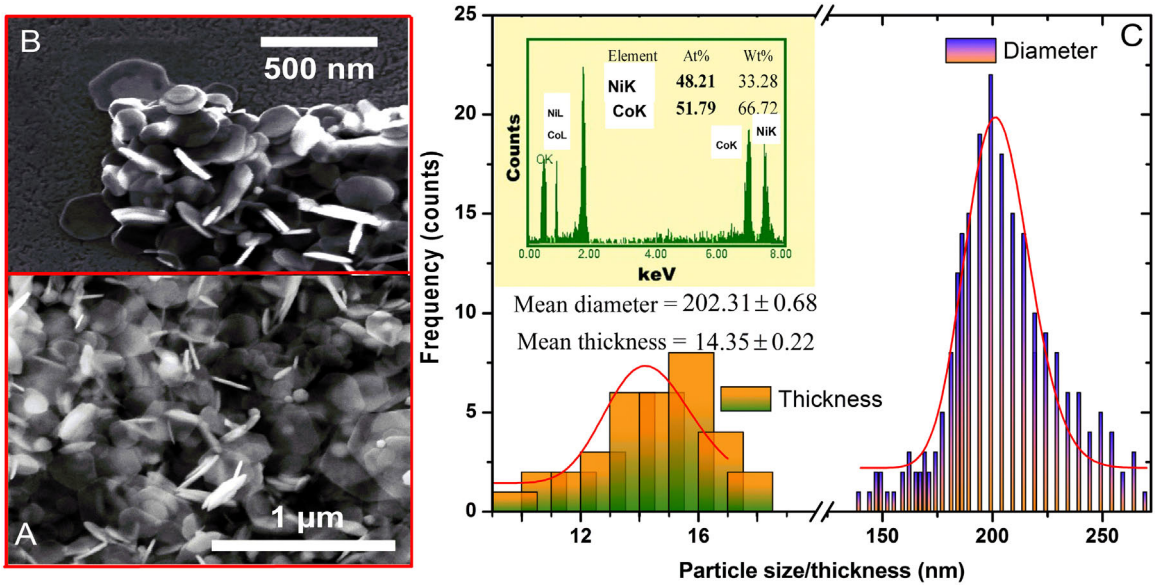

Fig. 1. Clockwise from left: (A and B) low- and high resolution FESEM images of CoNi hexagonal nanoplatelets, (C) average size (diameter) and thickness distribution curves of nanoplatelets and (C, inset) EDX spectra of the sample confirming the 1:1 composition.

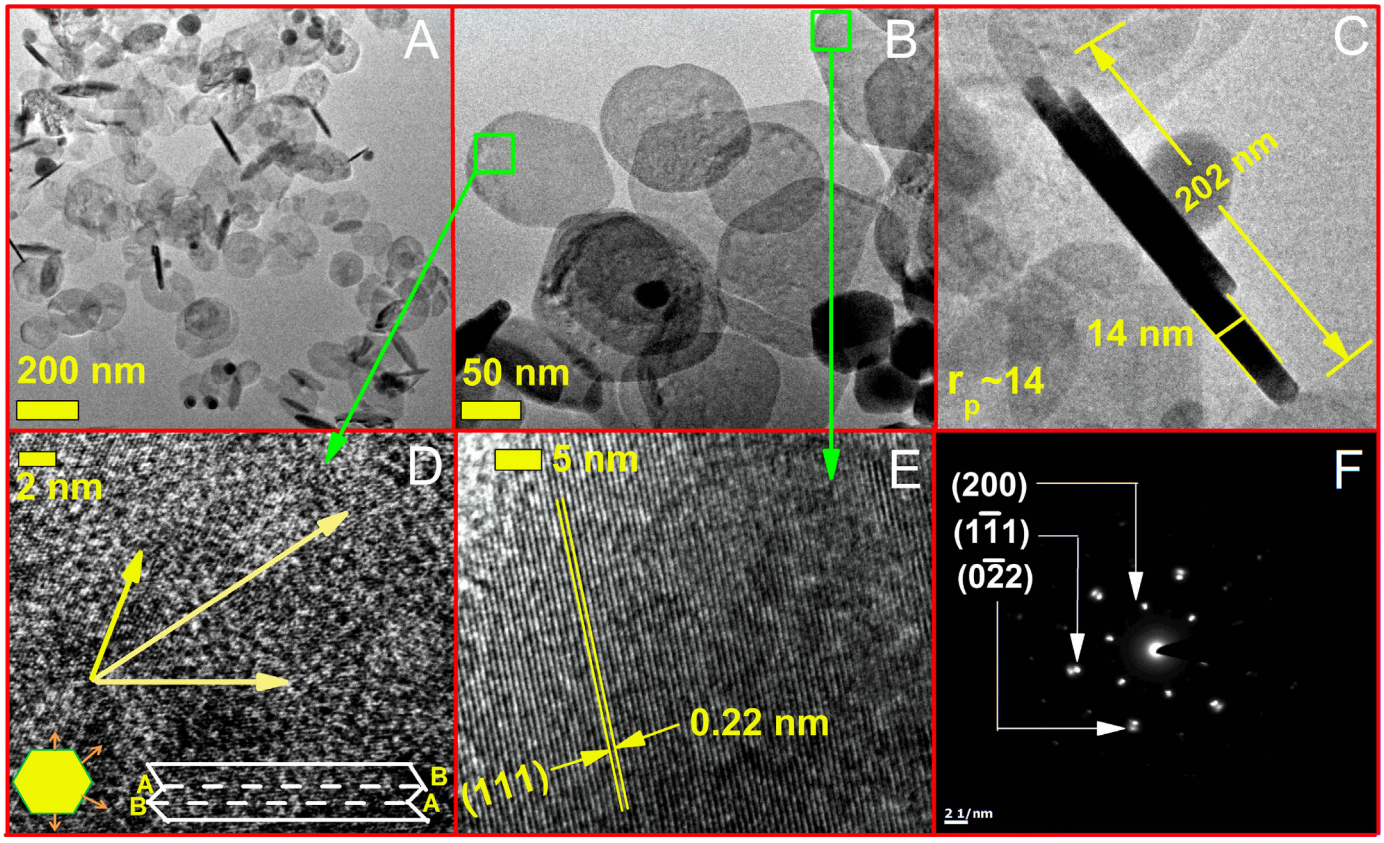

Fig. 2. (A, B) Low and high magnification TEM images of CoNi nanoplatelets, (C) cross section of individual nanoplatelet with aspect ratio of 14, (D, E) HRTEM of selected spots with schematic of growth direction, and (F) selected area diffraction pattern (SAED) of nanoplatelets.

3. Results and discussion

Morphology, average size and composition of CoNi hexagonal nanoplatelets are confirmed by FESEM studies performed using Quanta FEG® (FEI) field emission scanning electron microscope. Fig. 1 (A and B) illustrates the low and high magnification FESEM images along with particle size distribution histogram. The mean radius and thickness of nanoplatelets are measured assuming log-normal distribution and found to be 202 nm and 14.3 nm, respectively. It is evident that the distribution is nearly monodisperse with distinguished hexagonal shape of platelets.

The EDAX spectra further shows that the nanoplatelets attained compositional homogeneity with nearly 1:1 Ni and Co atomic ratio. Similar structural features are also extracted from the TEM (Technai F20®, FEI) images of Fig. 2 in which individual nanoplatelets are viewed both front and sidewise. The typical aspect ratio (r_p) of plates