Fibre Laser Processing of Nanocomposite Nd2Fe14B/Fe Magnets - A Route to Additive Manufacturing?

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Introduction

The production of bulk nanocomposite materials is a great challenge faced by the rare earth magnet scientific community. In this work the feasibility of an additive manufacturing approach utilising laser annealing and the advantages and disadvantages entailed are being investigated.

In the suggested approach, amorphous or partially crystalline precursor material is consolidated layer by layer and then heat treated by laser irradiation to precipitate the desired nanocomposite structure, using the bulk of the material as a heat sink to facilitate the rapid thermal processing required.

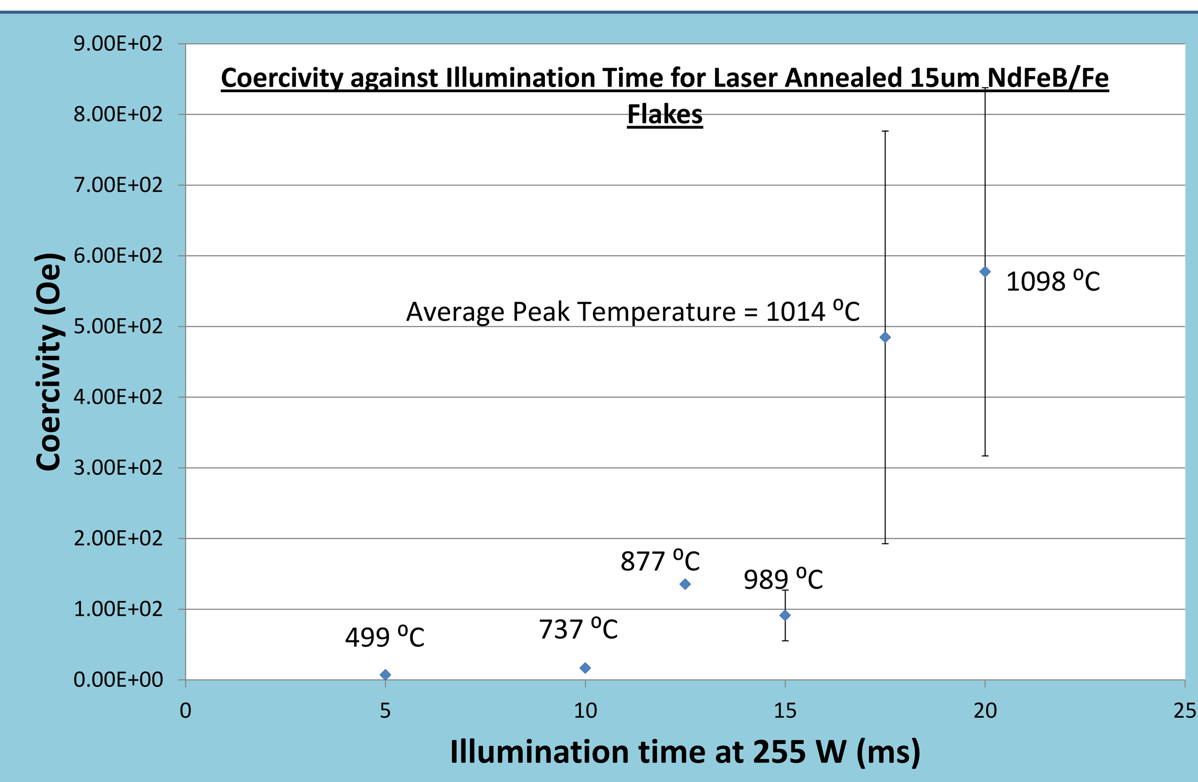
Additive manufacturing techniques offer potential advantages in waste reduction, unique shaping potential and the possibility of functionally graded materials.

The current work focusses on the feasibility of using laser annealing for forming nanocomposite structures in successive layers.

Laser annealing Amorphous NdFeB/Fe Powder Flakes – Experimental

Melt spun flakes/powder of an Fe+Co rich composition approximately 15 µm thick were supplied by Magnequench Ltd. The powder was confirmed as **amorphous** by X-ray diffraction. Batches of powder were then irradiated by a 3mm 1/e^2 diameter Gaussian laser spot with varying powers from 180 – 255 W and top hat pulse illumination times from 10-60 ms. Peak temperature was chosen as the metric to describe each heat treatment as the cooling curve was largely material dependant and shared the same shape across different laser powers/ illumination times.

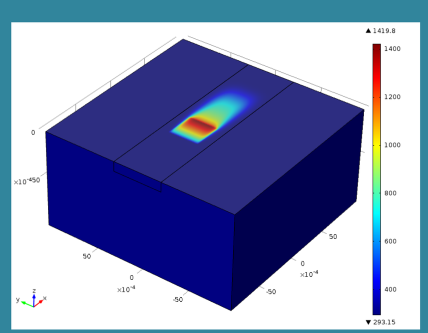
The top layer of each batch of flakes was removed with adhesive tape and the flakes were then characterised by VSM. Some were also chosen for TEM examination.



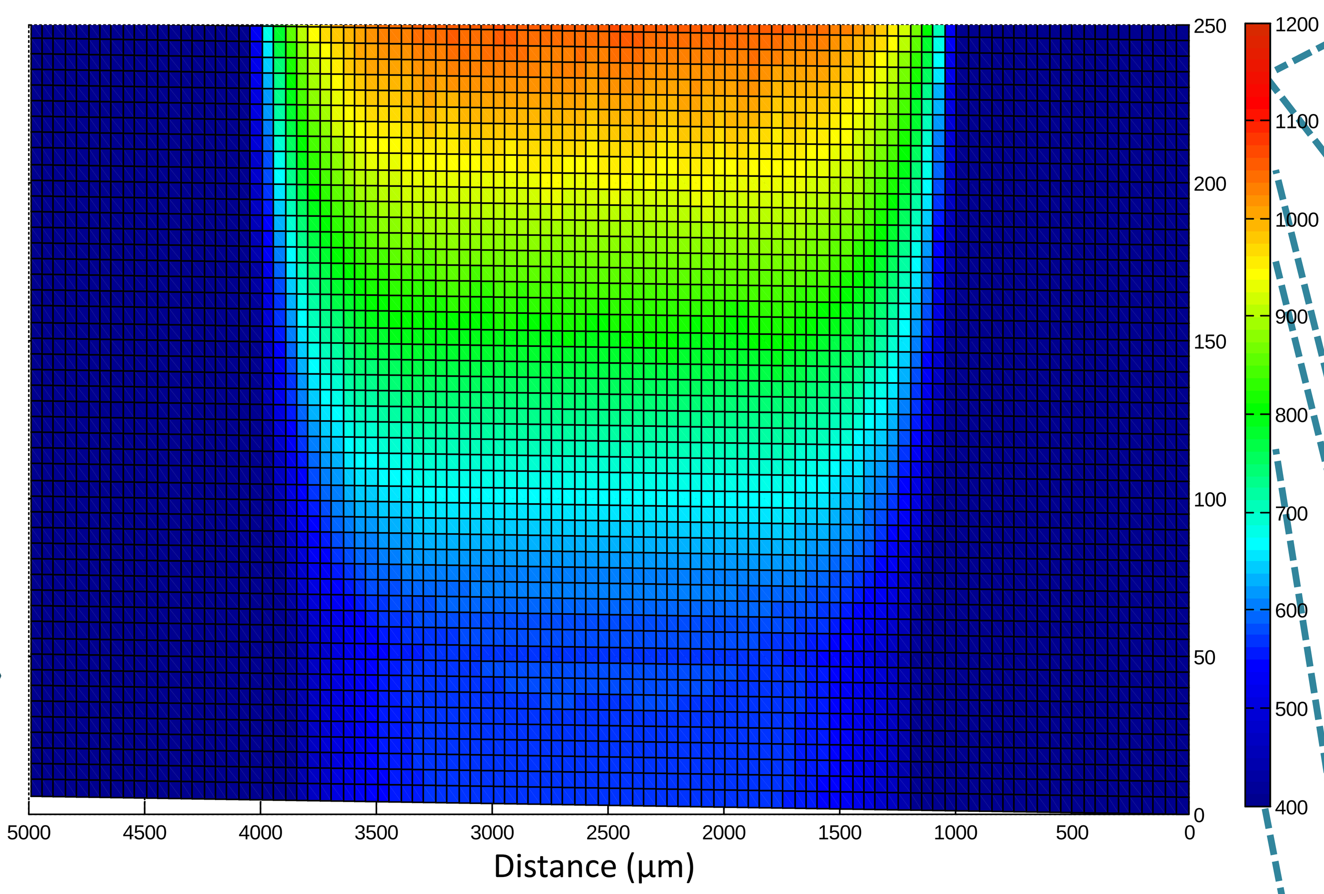
Simulation

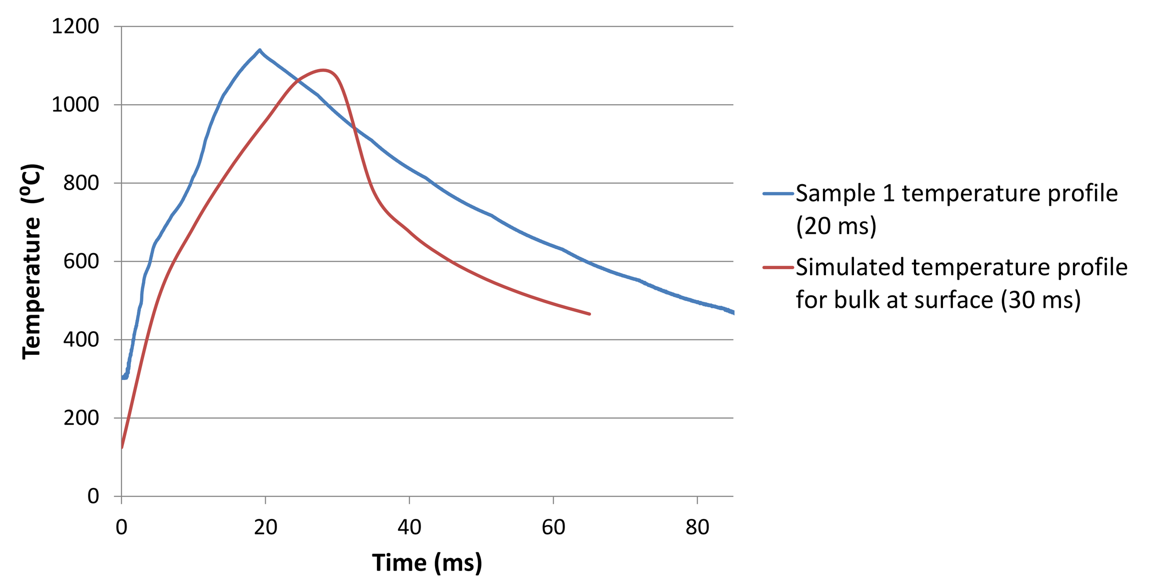
A finite element analysis thermal model of a square top hat pulse traversing the surface of NdFeB was developed using COMSOL multiphysics®. In the model a 3mm square top hat laser spot traverses the surface at 0.1 m/s. This is equivalent to a dwell time of 30 ms and a total power of 306 W. This is higher than experimental parameters to account for increased heat dissipation in a bulk material.

Extracting from this the maximum temperature reached at each point in a cross-section of the material we can correlate laser annealing trials on powder flakes with the thermal histories of elements at various depths through a bulk material.

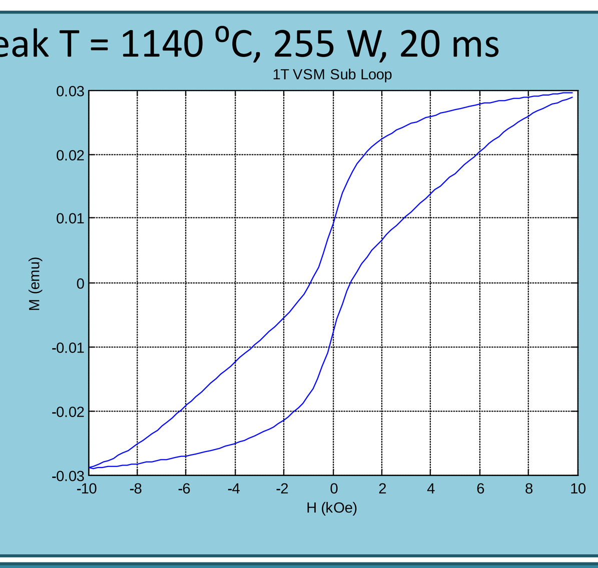


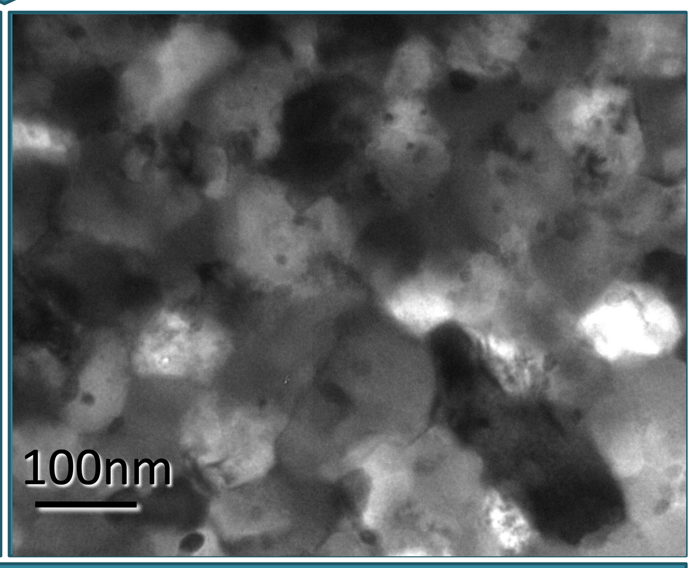
Cross-section of Peak Temperature Reached During Cycle





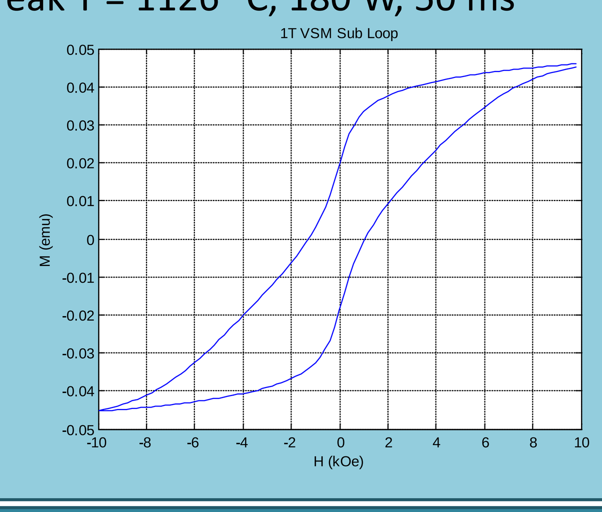
Peak T = 1140 °C, 255 W, 20 ms

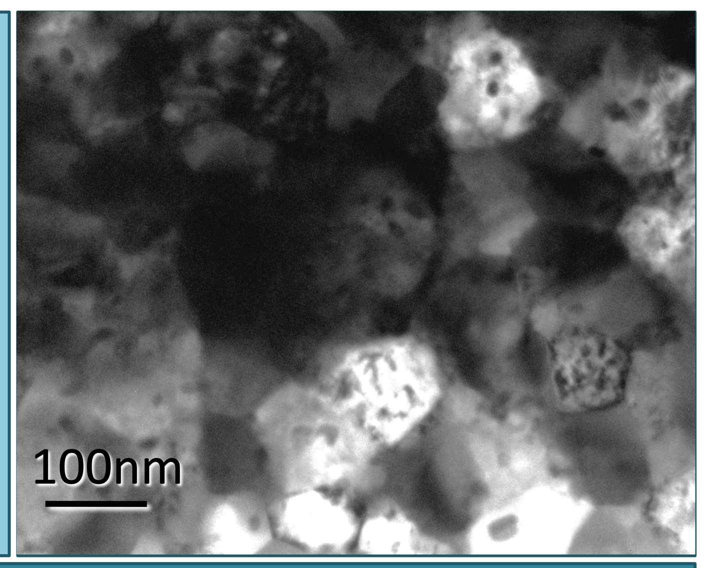




Sample 1 – Peak T = 1140 °C after illumination at 255 W for 20 ms. TEM image to the right shows the crystal structure in a region close to the centre of the beam which also exhibits large grains 50-100 nm in diameter interspersed with grains <10nm in diameter.

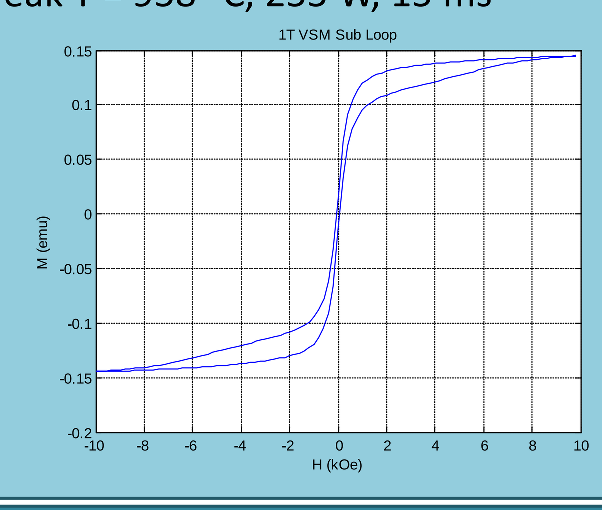
Peak T = 1126 °C, 180 W, 50 ms



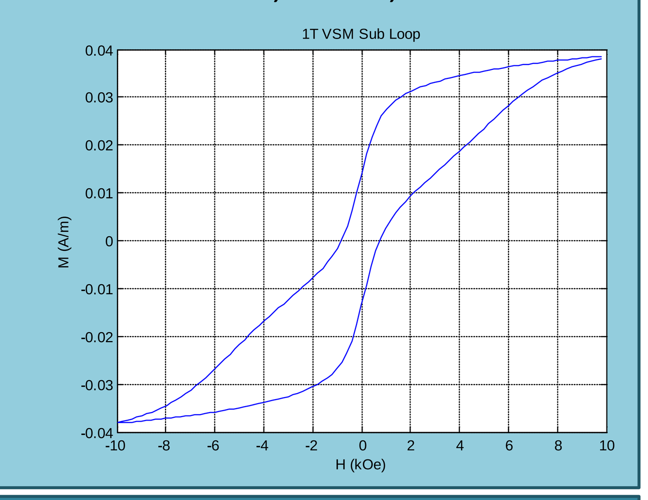


Sample 1 – Peak T reached = 1126 °C after illumination at 180 W for 50 ms. TEM image to the right shows the crystal structure in a region close to the centre of the beam which exhibits large grains 50 - 100 nm in diameter interspersed with grains <10nm in diameter.

Peak T = 958 °C, 255 W, 15 ms

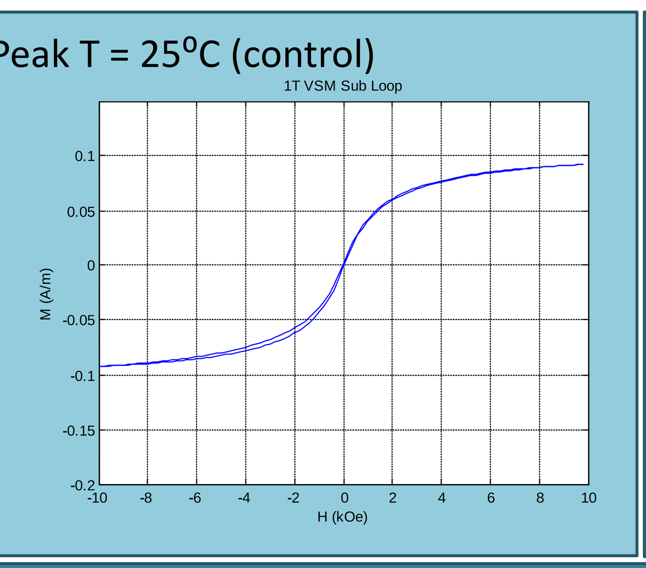


Peak T = 1063 °C, 255W, 17.5 ms

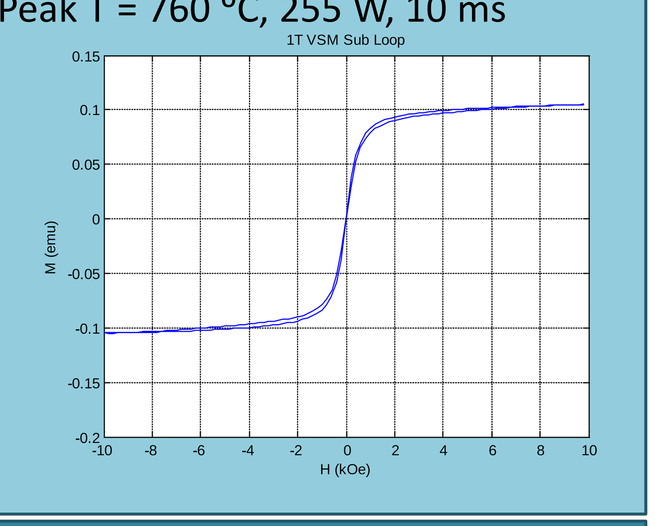


Samples 3 and 4 – Peak T reached = 958 °C and 1009 °C when illuminated for shorter periods at 255 W (15ms and 17.5 ms). The change in magnetic response is significant after a change of just over 100 °C

Peak T = 25°C (control)



Peak T = 760 °C, 255 W, 10 ms



Samples 5 and 6 – Peak T reached = room temperature and 760 °C when illuminated for 0ms and 10ms respectively. At a peak temperature of 760, over 100 °C above the crystallisation points of this material the hysteresis loop is similar to the control sample.

Conclusions

This study has demonstrated that the 'undertreated zone' between near optimal regions and unaffected regions is likely not as large as one might think for a surface laser heat treatment of bulk $Nd_2Fe_{14}B$/Fe. The transition from fully crystalline to unchanged occurs over a relatively short peak temperature interval, and the bulk of the material acting as a heat sink serves to produce a steep temperature gradient reducing the size of this region.

Unfortunately a Gaussian laser beam profile has led to data that is not as informative as a top hat beam profile would produce due to a distribution of treatments being applied to each sample batch. As such the hysteresis loops shown are a convolution of under, over and optimally treated material. Further studies with top hat beam profiles are required.

On-going and Future Work

- High speed amorphous NdFeB material consolidation technique
- Further laser annealing studies with a top hat beam profile
- Investigation into the effects of a second heat treatment at lower intensity from successive layers

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