Institution: Brunel University London		
Unit of Assessment: 12 Engineering		
Title of case study: Developing business using niobium-based grain refiner		
Period when the underpinning research was undertaken: 2014-2016		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Hari-Babu Nadendla	**Role(s) (e.g. job title):** Professor	**Period(s) employed by submitting HEI:** 12/2006-present
Period when the claimed impact occurred: 2016 – December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

Prof Nadendla's research on using niobium as a grain refiner for casting aluminium alloys has offered sustainable and innovative solutions for the aerospace and automotive industries: CBMM, the largest producer of ferroniobium (a form of niobium) who supplies 70% of the global market, has been significantly influenced by Prof Nadendla's research. CBMM was able to realise their business strategy and expedite their market growth by broadening their focus from predominantly steel to aluminium. They saw Prof Nadendla's research as providing solutions for the technical and financial challenges that the current adoption of large aluminium alloy casting presents for the automotive industry. In 2018, CBMM commercialised and made the first sale of niobium as a grain refiner in casting aluminium. [text removed for publication] CBMM's financial commitment is clear: they have established a new dedicated team within their Aluminium Programme and invested in 5 offices and 60 staff worldwide, who are solely dedicated to promoting and communicating the benefits of niobium.

Another beneficiary of Prof Nadendla's research is Grainger & Worrall. They are UK-based and operate the largest prototype foundry in Europe. They assert that Prof Nadendla's research has significantly contributed to their strong position in the European/Worldwide lightweight casting market in producing large and complex cast structures. They are able to cast very complex parts like engines and gear boxes for their automotive and aerospace clients using Prof Nadendla's research without as much waste metal as before. They confirm that Prof Nadendla's casting method is so efficient that they were able to remove a step in their manufacturing process, significantly reducing their energy and carbon footprint.

2. Underpinning research (indicative maximum 500 words)

Brunel has been a major contributor to research on nucleation-based solidification including liquid metal engineering, in particular innovative technologies for enhancing and controlling nucleation through physical and chemical methods. Nucleation is the first step in solid phase formation from the liquid and these nuclei grow to complete phase transformation from liquid to complete solid. If the nuclei density is increased in the melt, it leads to a fine grain structure.

The grain refinement process is aimed at enhancing nuclei density to obtain a fine grain structure in the solid. These fine grain structured alloys exhibit good mechanical properties including strength and toughness. There are two approaches to grain refinement. One is a chemical method in which ex-situ chemical compounds are added to the liquid and the other is the physical approach in which external fields are applied to break dendrites during solidification.

Since 2011, Prof Nadendla and his team have been specialising in chemical methods for grain refinement in heterogeneous nucleation processes during solidification for aluminium and magnesium alloys.

Prof Nadendla and his team have examined the benefits of a new niobium-based grain refiner for use with aluminium (Ref 1, Ref 2), confirming that the effect of the new refiner on as-cast microstructures is considerable and results in improved fluidity, so thinner sections can be cast with lower weight and reduced defects.

The addition of the Nb-B grain refiner can efficiently and reliably refine the microstructural features of Al-Si cast alloys confirming the chemical stability of the Nb-based compounds.

Liquid feeding into complex shaped regions is easier due to the increased density of nucleation sites that grow simultaneously instead of growth originating from the wall of the mould. Mechanical properties are uniform across the thickness of the casting due to the uniform grain structure. It enables the end user to design the engineering component more accurately and to contemplate much thinner structural sections (e.g. for the frames of car doors). It is applicable to castings produced at a wide range of cooling rates. The industry can apply this method in various processes such as investment casting, high pressure die casting, low pressure die casting, permanent mould casting and sand castings. It has been successfully demonstrated (Ref 3) that this could be applied in the direct chill casting process, which is typically used for wrought products.

Prof Nadendla's research confirms that the Nb-based grain refiner offers the end user the following benefits:

- improved castability of a wide range of aluminium alloys
- no hot-tearing, a common problem in castings
- improved tensile strength and ductility
- improved homogeneity in mechanical properties across the component
- tolerates high impurity levels (aluminium scrap can now be manufactured with superior properties)
- reduced defects thus minimising the scrap rate and maximising production.

3. References to the research (indicative maximum of six references)

Ref 1: Nowak, M., Bolzoni, L. and Nadendla, HB. (2014) 'Grain refinement of Al-Si alloys by Nb-B inoculation. Part I: concept development and effect on binary alloys'. *Materials and Design*, 66 (PA). pp.366-375. ISSN: 1873-4197 https://doi.org/10.1016/j.matdes.2014.08.066

Ref 2: L.Bolzoni, M.Nowak and N.Hari Babu (2014) Grain refinement of Al–Si alloys by Nb–B inoculation. Part II: Application to commercial alloys, *Materials & Design (1980-2015),* 66 (376-383) https://doi.org/10.1016/j.matdes.2014.08.067

Ref 3: Bolzoni, L., Xia, M. and Nadendla, H. (2016) 'Formation of equiaxed crystal structures in directionally solidified Al-Si alloys using Nb-based heterogeneous nuclei'. *Scientific Reports*, 6 (1). pp. 39554. ISSN: 2045-2322 https://doi.org/10.1038/srep39554

Grant:

Grain refiner for high performance lightweight aluminium automotive castings (101177): GBP340,041 funded by Innovate UK from Nov 2012 to Oct 2014.

4. Details of the impact (indicative maximum 750 words)

Prof Nadendla and his team's innovative method of using niobium as a grain refiner has provided efficient and reliable solutions for casting aluminium alloys for aerospace and automotive industries in particular, generating value from production to manufacturing in the global market.

Creating business, growing market, realising business strategies

Companhia Brasileira de Metalurgia e Mineração (CBMM) was one of the first to recognise the benefits of commercialising Prof Nadendla's research. CBMM is a Brazilian company that specialises in the processing and technology of niobium; it is the largest producer of ferroniobium (a form of niobium), supplying over 70% of the market and selling to over 50 countries. [text removed for publication]

The automotive industry has very strict EU automobile emission targets: the EU fleet-wide average emission target for new cars from 2020-21 will be 95gCO_2/km, greatly reduced from 130gCO_2/km between 2015 and 2019.

Lightweight materials are essential for increasing fuel efficiency of vehicles while maintaining their safety and performance. Prof Nadendla's method enables the manufacture of lighter aluminium parts than can be achieved by refining the microstructure in the cast product, reducing the overall weight of vehicles. Because it takes less energy to accelerate a lighter car than a heavier one, lightweight materials are important to both automakers and auto buyers. When automakers reduce the weight of a vehicle by 10%, they boost the fuel economy of that vehicle by 6-8%.

This work was internationally recognised when Prof Nadendla and his team received The Charles Hatchett Award in 2016 (E2). The Charles Hatchett Award, first presented in 1979, recognises internationally renowned niobium technology and is administered by the Metals Society on behalf of Companhia Brasileira de Metalurgia e Mineração (CBMM).

CBMM's Director of Technology stated that '…the important thing is to have the right material in the right place. There are technical and cost challenges to the adoption of large aluminium alloy castings, such as engine blocks, which include efficiently filling the moulds during the casting process. The Nb-B [Niobium diboride] inoculant refines the grains, improving the fluidity of the material being cast, and therefore making it easier to completely fill the moulds, leading to a higher integrity product. It is now up to the supply chain to act to ensure the adoption of this exciting new technology.' (E2)

Subsequently, CBMM has 'financially committed to exploring niobium in the aluminium market worldwide' since 2017, applying his research methods and communicating the advantage of using niobium.

Prof Nadendla's research has enabled them to realise their strategy and ambition to grow the niobium market in the world: in the automotive area, the highlight is the application of niobium in cast aluminium. CBMM commercialised and made the first sale of niobium as a grain refiner in casting aluminium for a niche prototype application in 2018. (E3) [text removed for publication]

In addition, BETA Technology, a technology consulting firm, who has been working with CBMM for 35 years to help them develop new markets for niobium in the metal sectors, confirms how Prof Nadendla's research has 'helped broaden CBMM's market focus from being predominantly related to steel, to one that has interests in aluminium.' (E5)

[text removed for publication]

This was possible because 'CBMM has developed its own in-house understanding in aluminium casting and processing, and its application to a broader range of automotive parts.' (E5) They also had to establish a new dedicated team within their Aluminium Programme and invested in '5 offices and 60 staff worldwide' solely dedicated to promoting and communicating the benefits of niobium. (E3) [text removed for publication]

Increasing Applicability While Reducing Scrap Metals

CBMM's first sale of niobium as a grain refiner was to Grainger & Worrall (UK), the largest prototype foundry in Europe, specialising in casting special and complex parts that are difficult to produce, such as cylinder blocks for heavy vehicles and gearboxes, for the automotive, aerospace and marine sectors. Grainger & Worrall has been using Prof Nadendla's research to refine microstructural features of Al-Si cast alloys, which is key to wider commercial applications,

and to enhance structural integrity. They cast large complex aluminium casting structures for their automotive and aerospace clients (e.g. engines and gear boxes). (E6)

Acknowledging the impact of Prof Nadendla's research, Grainger & Worrall states that 'it has significantly contributed to their [sic] strong position in the European/Worldwide lightweight casting market, in particular in producing large cast structures.' (E6)

The advantage of the technology is not limited to casting complex parts. Foundry production requires a complex multi-step process and the technical specification of each process varies greatly; the more complicated a product is, the more likely they are prone to casting defects. However, Prof Nadendla's casting method is so efficient that it has removed a step in manufacturing, significantly reducing their energy and carbon footprint while at the same time reducing their wastage:

> *The developed alloy used in large cast structures no longer needs additional tempering heat input to achieve mechanical properties, as is now at optimum condition as cast. This has saved time and significant cost, whilst reducing energy use, supporting the company's mission strategy to reduce its carbon footprint. (E6)*

5. Sources to corroborate the impact (indicative maximum of 10 references)

E1) Text removed for publication

E2) The 2016 Charles Hatchett Award, 'Novel research on cast aluminium products wins international award', http://www.charles-hatchett.com/news/2016-charles-hatchett-award-winners-announced

E3) Corroborating letter from CBMM

E4) Text removed for publication

E5) Corroborating letter from BETA Technology

E6) Corroborating letter from Grainger & Worrall