Institution: University of Dundee		
Unit of Assessment: UoA 12 Engineering		
Title of case study: The development of high value alloys and manufacturing techniques for automotive and power industries by improving continuous casting technology		
Period when the underpinning research was undertaken: Oct. 2011 – Oct. 2017		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Amin Abdolvand	**Role(s) (e.g. job title):** Professor (Chair of Functional Materials & Photonics)	**Period(s) employed by submitting HEI:** 2008 – to date
Period when the claimed impact occurred: 2013 – Oct. 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Rautomead develop, design and provide unique continuous casting equipment for the non-ferrous and precious metals industries globally. A partnership with the University of Dundee has led to the development of new alloys with reduced costs, simplification of manufacturing processes and shorter lead-times. This allowed Rautomead's customers to enter or develop new markets across the world. The partnership has also enabled Rautomead to substantially improve quality, resulting in reduced risk of consumer returns and the protection of the Rautomead brand. These research-based outcomes represent a multimillion-pound saving for the company.

2. Underpinning research

Prior to its involvement with the University of Dundee (UoD), Rautomead product and process development was largely empirically based, utilising its in-house facilities and the expertise and experience of its staff. Since October 2011, the company has worked extensively with UoD in its research and development (R&D) efforts, with activities including materials characterisation and development work. Research into materials characterisation is of paramount importance to Rautomead since this is the process by which the physical, chemical and/or structural properties of alloys are determined. This work was enabled through an Innovate UK award led by Professor Amin Abdolvand (Knowledge Transfer Partnership (KTP) Grant number: 8747), a KTP Associate (2012-2014), and two subsequent Technology Support Agreements (2014-2017 and 2017-2020).

The KTP project was key in crystallising the R&D activities between the two organisations with set objectives and commercial goals. The aim was to process new complex high-performance alloys by improving the capability and performance of continuous casting machinery (Figure 1). This initiative with a modest budget (£95k – 50% Innovate UK and 50% Scottish Funding Council) led to a substantial multimillion end value achieved as noted in section 4 and also outlined in the attached Letter of Support from the company **[E1]**.

The key underpinning research activities were experimental in nature:

- The addition of lead (Pb) to brass (alloy of copper and zinc) increased its machinability and corrosion resistance, enabling its applications in marine environments (to prevent biofouling) and as electrical cabling within wind turbines for renewable energy applications. The research performed within **[R1]** demonstrated

the unique horizontal-setup processing conditions which enabled the casting of high-volume, high-quality (characterised by a high homogeneity), Pb-brass alloy at Rautomead, leading on to the development and commercialisation of Pb-brass casting equipment.

- Improvement to the copper (Cu) alloy casting quality was demonstrated within **[R2]**, indicated by increases to material elongation and a smaller metal grain structure. This was obtained from an investigation into the processing parameters such as the cooling fluid flow (influencing metal cooling) and the casting withdraw rate (which influences the product yield). The research enabled improvements in the efficiency of casting equipment used in the fabrication of copper-tin-phosphorus (Cu-Sn-P) that is applied for corrosion resistance marine applications; oxygen-free-Cu which is used for electrical high data rate transmission cabling; and copper-zinc (Cu-Zn) used in electronics applications. Collectively the research contributed to the commercialisation of the casting equipment for these alloys by Rautomead.

- Further investigations into casting speed were made to identify casting improvements for the alloys of copper and magnesium (Cu-Mg) applied in high-speed rail trolley cabling and aluminium-brass (Al-brass) which is used in subsea and propeller construction **[R3]**. Alterations to the casting withdrawal pulse setting were applied (for control of material quality), in order to identify improved material performance and casting conditions. The research enabled Rautomead to reduce manufacturing turnaround for the alloys leading to the commercialisation of new casting equipment.

In summary, the underpinning research on the development of high value alloys established and consolidated strong links with Rautomead. The research enabled the transfer of new concepts and technology from laboratory into the manufacturing process. Material characterisation is now part of the company's "customer experience", particularly where new alloys are casted. This has assisted Rautomead in maintaining their international visibility [e.g. **R4-R6**] and market leading position for non-ferrous alloys.

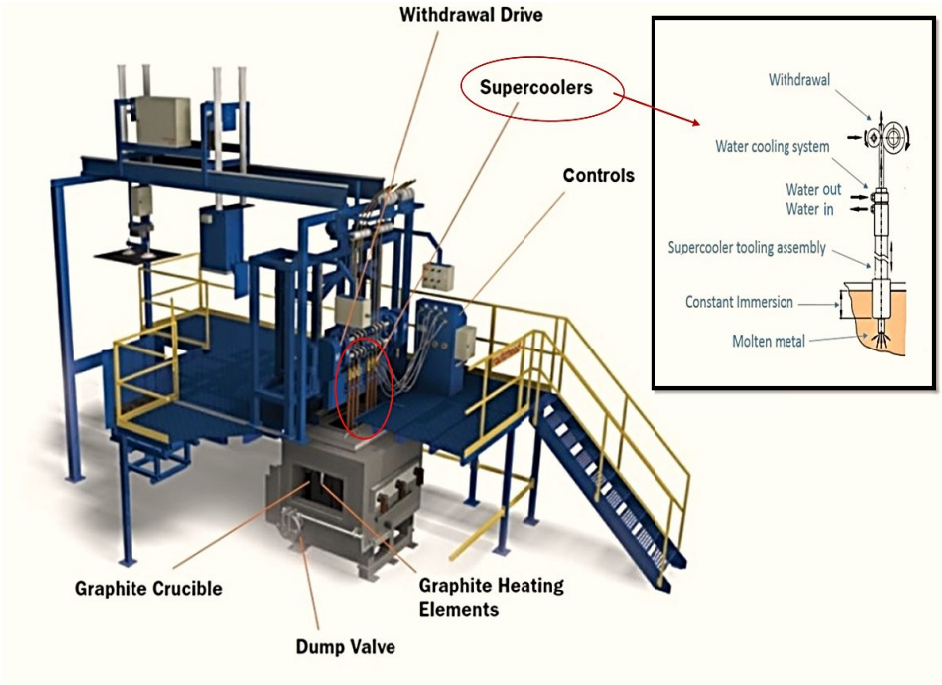

Figure 1. Schematic of continuous Rod casting machine. Rautomead sells between 5 and 10 machines per year **[E1]**. Image courtesy of Rautomead.

3. References to the research

[R1] Bagherian, E-R, Fan, Y, Cooper, M, Frame, B & **Abdolvand, A** (2016) 'Investigation of the distribution of lead in three different combinations of brass feedstock', *International Journal of Metalcasting*, vol. 10, no. 3, pp. 322-328. DOI: 10.1007/s40962-016-0055-1

[R2] Bagherian, E-R, Fan, Y, Cooper, M, Frame, B & **Abdolvand, A** (2016) 'Effect of water flow rate, casting speed, alloying elements and pull distance on tensile strength, elongation percentage and microstructure of continuous cast copper alloys', *Metallurgical Research and Technology*, vol. 113, no. 3, 308. DOI: 10.1051/metal/2016006

[R3] Bagherian, E-R, Fan, Y, Cooper, M, Frame, B & **Abdolvand, A** (2016) 'Effect of melt temperature, cleanout cycle, continuous casting direction (horizontal/vertical) and super-cooler size on tensile strength, elongation percentage and microstructure of continuous cast copper alloys', *Metallurgical Research and Technology*, vol. 113, no. 5, 502. DOI: 10.1051/metal/2016030

[R4] Bagherian, E-R, Bell, C, Cooper, M, Fan, Y, Frame, B & **Abdolvand, A** (2014) Influence of casting speed on the structure and mechanical properties of continuous cast DHP copper tube. in *METAL 2014: 23rd International Conference on Metallurgy and Materials, Conference Proceedings.* TANGER Ltd., pp. 1163-1168, 23rd International Conference on Metallurgy and Materials, Brno, Czech Republic, 21/05/14. Available at: http://metal2013.tanger.cz/files/proceedings/17/reports/2437.pdf

[R5] Bagherian, ER, Fan, Y, Cooper, M, Frame, B & **Abdolvand, A** (2016) Effect of antimony addition relative to microstructure and mechanical properties of continuous cast lead alloy. in *METAL 2016: 25th Anniversary International Conference on Metallurgy and Materials.* TANGER Ltd., pp. 1294-1300, 25th International Conference on Metallurgy and Materials METAL 2016, Brno, Czech Republic, 25/05/16. Available at: https://www.confer.cz/metal/2016/1792-effect-of-antimony-addition-relative-to-microstructure-and-mechanical-properties-of-continous-cast-lead-alloy [Accessed 19 March 2021].

[R6] Bagherian, ER, Fan, Y, Cooper, M, Frame, B & **Abdolvand, A** (2016) Analysis and quantification of mechanical properties of various DHP copper tubes manufacturing processes using drift expanding test. in *METAL 2016 - 25th Anniversary International Conference on Metallurgy and Materials, Conference Proceedings.* TANGER Ltd., pp. 1345-1350, 25th International Conference on Metallurgy and Materials, METAL 2016, Brno, Czech Republic, 25/05/16. Available at: https://www.confer.cz/metal/2016/1957-analysis-and-quantification-of-mechanical-properties-of-various-dhp-copper-tubes-manufacturing-processes-using-drift-expanding-test [Accessed 19 March 2021].

Funding awards:
KTP Grant number: 8747 (Oct 2011-Oct 2014), GBP 94,936.00

4. Details of the impact

Markets directly influenced by research activities

Rautomead is an established supplier of unique equipment in the continuous casting, wire, and cable industry, with a global reputation for developing and providing equipment to produce high-quality materials. Target customers for the products developed under the aegis of this impact case study included a number of leading Japanese, European and Chinese wire and cable providers. The companies will pay and engage to enhance their market position and/or develop new markets. In particular, Rautomead's ability to manufacture products to satisfy the demand generated by developments in the electric vehicle industry made it an attractive proposition for customers.

The work with UoD allowed Rautomead to reliably and efficiently verify the uniqueness and quality of new machines, technology and processes for its customers across the world. Since working with UoD, access to research skills has opened new market opportunities - particularly in Japan, where technical expertise and detail are especially valued; it has also enabled Rautomead to provide a known, evidenced and proven solution allowing them to increase the margins for their global equipment sales **[E1]**.

This has been especially valuable in commercial negotiations, where the balance of technical risk, and hence leverage for customer discount has moved significantly towards Rautomead's favour. In one case this led to an improved gross margin capability in the region of £200k over their previous similar projects. Considering that Rautomead sell between 5-10 machines per year, Rautomead estimate that this R&D partnership is impacting their bottom line somewhere between £1-2M per year **[E1]**.

Improved production lead times

Equipment sales are often underpinned by Rautomead performing *'casting-trials'*, where a quantity of material is cast, usually for the first time, as a means of proving both product and process capability. The research has enabled Rautomead to provide their customers with material characterisation information from casting trials, something they were not able to do previously, but which is of significant value to the customer and which feeds into subsequent process optimisation and equipment design modification **[E1]**.

As a direct result of this work, the production lead time has been reduced by 25%, leading to time and material resource savings valued at £180,000 (as in the example of Cu-Zn alloy used in robot welding). According to Rautomead, the company's culture has altered in respect of the evaluation of untested alloys, leading to "*a considerable reduction in numbers of costly trials performed"* **[E1]**.

Another specific scientific example of the impact pursued through this approach is the recent identification of adverse chemical reactions of a nickel-chromium (Ni-Cr) alloy that is used in gas turbine blade manufacture. The existing (boron based) casting die at Rautomead prevented its casting, hence a further investigation of alternative casting die materials to enable its casting (Ca-ZrO_3) was identified. This has led to considerable saving in time and material resources in trials **[E1]**.

Enhanced casting quality/yield

The UoD casting expertise and analytical skills has enabled Rautomead to advance their technical capabilities **[R1-R3]**. Enhancements include improving casting speed for oxygen-free-Cu (OFCu) rod used in data communication applications and particle accelerators, by identifying optimum conditions for increased casting yield and high quality **[R2]**. Since working with UoD, over the last 5 – 8 years the manufacturing yield of OFCu at Rautomead has approximately doubled (from 2.5 m/min to 5 m/min) enabling greater volumes of cast rod at reduced equipment costs **[E1]**.

Development of new products and services

Since working with the UoD, Rautomead has improved its evidence-based materials characterisation capability, allowing Rautomead to leverage technical innovations from its other R&D activities. This has led to the knowledge on the casting of new alloys to increase Rautomead's offerings (e.g., alloys such as CuMg, CuSn and CuAg). Key examples include high value alloys Cu-Cr-Zr and Cu-Zr, which display high electrical conductivity and post-processing material strengthening **[R2]** and have a wide range of applications, e.g. as trolley wire within electric trains **[E1]**.

The work has contributed to a new piece of equipment which to date has resulted in 2 machine sales of this machine variant to Japanese customers (valued at €954,000; Date: 2016), and with a projected future sale of more than 10 machines over the next 2-3 years.

Other examples include Pb-brass alloy used in corrosion resistance renewables (valued at €538,000 machine sale to Korea; Date: 2017), and Al-bronze alloy for sub-sea applications (valued at €1,400,000 machine sale to Spain; Date: 2017) **[E1]**.

New company offerings to customers
Rautomead are now able to provide substantial material characterisation both during and after the actual trial-casting process. This has provided a significant impact to the competitive position for the company and its international image which includes:

- Advancement of the casting-trial process offered to customers due to improved characterisation techniques employed at UoD;

- Improved 'product plus material characterisation analysis' offering by Rautomead to customers, enabling significantly stronger technical and commercial selling of processing equipment;

- Enhanced technical image of the company within the market, as a company who can provide a proven and trustworthy solution to its customers, and considerable publicity through dissemination of the research by Rautomead at Trade Shows (e.g. International Foundry Trade Fair with Technical Forum (GIFA) that is globally attended by industrial experts and equipment supplies from across the casting/foundry industry, and Wire Association International Global Continuous Casting Forum - Atlanta, USA – that is a forum for professionals within continuous casting technology to meet and exchange innovative ideas.

The drive to improve casting ability further has led to the continued investment of a new KTP with UoD [Grant Number: 11042, Feb. 2018 – Feb. 2020] on the development of bespoke modelling and simulation tools into the design process for continuous casting machines, and a new part-time PhD studentship (2016-2022), focussing on using the modelling and simulation tools to address the demand for low weight copper alloy wiring for the rapidly evolving automotive, aerospace and high speed rail markets.

In summary, the global reach of the partnership is evidenced by the number and diversity of machine sales across the world within the REF period, covering Americas, the Far East, Asia and Europe. The R&D collaboration between Rautomead and UoD has grown significantly, with ongoing links in provision of two Technology Support Agreements, investment in student projects at PhD and MSc levels, placements and visits to and with Rautomead, the employment of additional UoD graduates by the company (Rautomead have increased their permanent staff by 10% since 2015), and the aforementioned new KTP with UoD. This partnership has been, and will continue to be, of key strategic importance to the parties **[E1]**.

5. Sources to corroborate the impact

[E1] Letter of support from Rautomead and appendix (12th October 2020).