Research and Needs Analysis on Metal Additive Manufacturing

D1.1 – Report

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Executive Summary

Additive Manufacturing (AM) is stated as one of the key enabling technologies that will shape new approaches to manufacturing and the products and factories of the future [1]. However, the increasingly complex nature of AM products and production processes necessitate a highly qualified workforce with a new skill set. The availability of employees with this highly specialised skill set is limited and not only is there a shortage of engineers with proficiency in AM but there is also a lack of suitable training courses to address this skills gap [2].

A number of barriers to increased utilisation of the metal additive manufacturing technologies have been identified with education being frequently highlighted by industry as one of the most important issues [2].

This report has reviewed and analysed the state of the AM industry as well as the needs of the key stakeholders in regards to the creation of an executive joint MSc in Metal Additive Manufacturing. The results from the online surveys and focus groups targeted at these key stakeholders, have clearly identified a cohort of people interested in this proposed master's course. It has recognised the preference for significant collaboration between industry and university to align the skills students learn to those required in an engineer working within the AM industry. Furthermore, this feedback has highlighted particular areas of the course syllabus and structure that are considered important to the success of the course.

Finally, the report has also identified that there are currently no masters level courses which focus solely on Metal AM, as the extremely limited number of current available courses worldwide (six) dedicating significant amounts of time to all materials, instead of focusing on one specific material type. There is therefore a need for a well-developed, industrially relevant master's course in metal additive manufacturing.

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1 Introduction

Additive Manufacturing (AM) is stated as one of the key enabling technologies that will shape new approaches to manufacturing and the products and factories of the future [1]. It is a rapidly growing and evolving field with the global market for additive manufacturing products and services growing by 29% in 2012 to over $2 billion and is predicted to be worth $10.8 billion by 2021 [3]. This presents substantial opportunities and challenges for both industry and academia alike.

Governments, collaborative research, and industrial initiatives in the UK and EU have published a significant number of reports recently (<5 years) reviewing the economic and strategic importance and the challenges associated with progressing and exploiting AM [4–9].

The development of AM technologies has the ability to revolutionise the manufacturing and consumer industries [1,10,11]. However, the increasingly complex nature of AM products and production processes necessitate a highly qualified workforce with a new skill set. The availability of employees with this highly specialised skill set is limited. Not only is there a shortage of engineers with proficiency in AM but there is also a lack of suitable training courses to address this skills gap [2,12].

In order to maximise the opportunities AM technologies provide, and for Europe to maintain its position as a major global player in this market, the lack of suitable training courses must be addressed. It is desirable that any training offer be designed following the co-operation between industry, local authorities, educational institutions and workers' organisations and is based on the real needs of the companies operating in this sector.

In order to achieve this the ADMIRE project will use this report to investigate the needs of the AM industry and prospective students to create of a joint MSc in Metal Additive Manufacturing.

2 Aims and Objectives

The aim of this report is to detail the state of the art within the Additive Manufacturing industry and latest developments in a multidisciplinary scope. This will include:

- A research analysis in additive manufacturing for the creation of a joint MSc in Metal Additive Manufacturing structured in modules at Cranfield University according to the European Qualification Framework (EQF).

- Collect Multidisciplinary data on the needs and feedback from the main AM stakeholders and companies at European level, namely from aerospace and defence, architecture and construction, energy, aviation and aerostructures, and automotive backgrounds.

- Collect needs from higher education institutes such as the Cranfield University, University of Birmingham, University of Bremen and Instituto Superior Tecnico and collect teaching staff feedback on the possible MSc.

- Collect feedback, expectations and future career perspectives from engineers, management, design and architecture and biomechanics undergraduate students on the possible enrolment in the MSc.

3 Current State of Additive Manufacturing Industry

3.1 What is Additive Manufacturing?

Additive Manufacturing (AM) is a term used to describe the production of three-dimension object by building up of material layer-upon-layer controlled by a computer. AM is a broad term that encompassed all additive techniques and materials: polymer, metallic, ceramic and composite.

There are a number of techniques which can be categorised as being made via additive manufacturing including, powder bed fusion, direct energy deposition, material jetting, binder jetting, material extrusion and sheet lamination. The two most widely used groups of techniques are powder bed fusion or direct energy deposition. Powder bed fusion technologies combine a method of fusion with a build platform containing the powdered material. This technique includes; selective laser sintering (SLS), selective laser melting (SLM) and electron beam melting (EBM). Direct energy deposition utilises a feed of material either in powder or wire with a fusion catalyst or heat source building directly onto a substrate. This technique includes direct metal deposition (DMD) and wire and arc additive manufacturing (WAAM).

3.2 The strategic importance of AM

Additive manufacturing has a strategic role to play in the future of the European high value manufacturing economy and has been the subject of a number of reports [4–9] assessing the state and future of the industry and identifying barriers to its full exploitation.

It is a rapidly growing and evolving field with the global market for additive manufacturing products and services growing by 29% in 2012 to over $2 billion and is predicted to be worth $10.8 billion by 2021 [3]. This presents substantial opportunities and challenges for both industry and academia alike. Competition between countries and companies to fully exploit this technology is fierce, with substantial rewards for those that lead the world in this technology. AM has the ability to revolutionise manufacturing in a number of industries, biomedical and aerospace to name two such industries and is sometimes referred to as part of the 4th Industrial revolution [11].

3.3 Why do we require a needs analysis

A needs analysis is required to discover what all the stakeholder groups need in order to maximise the potential of AM technology.

This includes finding out what skills are required by managers from their employees in order to progress in the industry, and finding out what prospective students want from a MSc course in metal AM. This is extremely important in order to design and implement an effective course that addresses the needs to the AM sector by providing the students with the pre-requisite skills to help exploit the technology.

The needs analysis has been conducted through a number of means including, online questionnaires and focus groups targeting specific stakeholder groups (prospective students, industry managers and higher education professionals), desk based research.

4 Surveys

4.1 Prospective students questionnaire

An online questionnaire was produced to sample the opinions of the prospective students' stakeholder group to a MSc course in Metal AM. A number of questions were asked and these are included in the Appendix. The full survey can be found at:
https://www.surveymonkey.com/r/ADMIRE_students

A selection of the results to the survey are included and discussed below.

4.1.1 Results

Table 1 shows the country of origin for all the responses to the questionnaire, illustrating the diverse range of European countries sampled.

Table 1 – Country of origin for responders

Country	%
Austria	1.23%
Denmark	1.23%
France	12.35%
Germany	18.52%
Greece	1.23%
Italy	2.47%
Portugal	12.35%
Turkey	1.23%
United Kingdom	37.04%
Other	12.35%

From this diverse range of students, the majority of those sampled showed that they had a limited amount of work experience (Figure 1), however, 49% stated that had experience of using an AM machine. In addition, 70% of respondees stated that their materials science knowledge was good, very good or excellent, however only 50% stated that their CAD/Design skills were of the same standard. This gives an indication of the level of background knowledge expected of the prospective students.

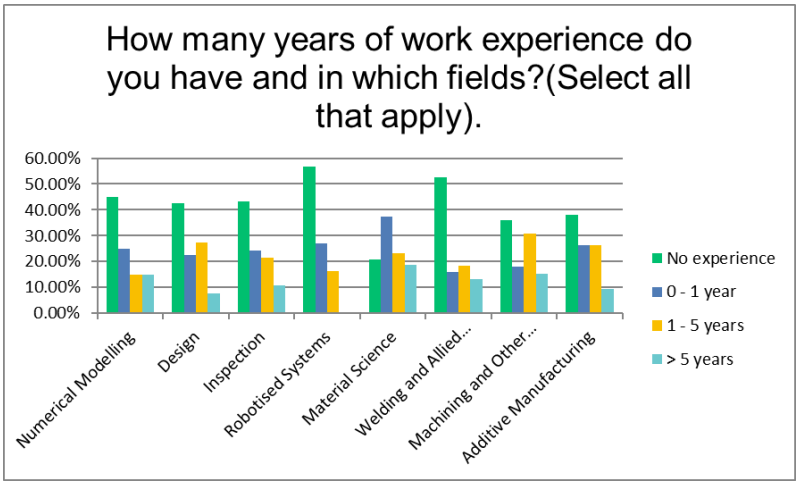

Figure 1 – Shows the level of work experience possessed by the prospective students.

Clearly one of the most important questions to ask prospective students is whether they have an interest in attending an MSc in metal additive manufacturing. Overwhelmingly, Figure 2 shows that, 70% of the 109 responders expressed an interest in doing this course. However, this should not be a surprise, as the responders filling out the questionnaire would be expected to have an interest in the AM industry.

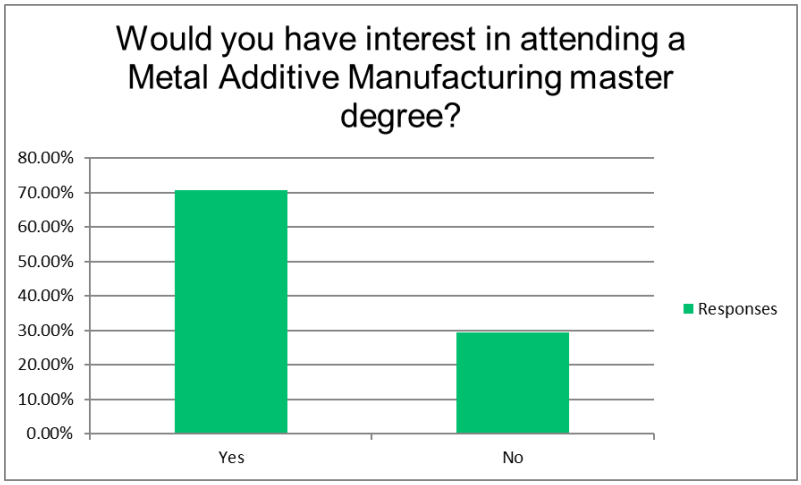

Figure 2 – Results from the student stakeholder questionnaire illustrating that the majority of people sampled would be interested in attending a Metal AM master's degree.

Table 2 – The reason the prospective students were interested in undertaking the course

Answer Choices	Responses
Possibility to get a specialisation in this technology;	64.7%
Possibility to learn new processes;	58.8%
Would like to work in AM technology in the future;	55.9%
There's a positive growth and uptake of AM technology in the European and International market;	52.9%
It's a new subject/topic;	33.8%
Other (please specify)	2.9%
I have no interest;	0.0%

Table 2 illustrates that the majority of students were interested in undertaking the course to gain a specialism in metal AM, learn about new processes in this industry, enter a growing market relaying on AM technology or to work in the AM sector. These are all strong drivers illustrating the students' interest for the course.

Furthermore, both Figure 3 and Figure 4 show that the vast majority of prospective students sampled want significant interaction with industry and thought that hands on experience of using an AM machine was important or very important so these must be considered when designing the course.

Figure 3 - Results from the student stakeholder questionnaire illustrating that the vast majority of people sampled would want significant interaction with industry through the course.

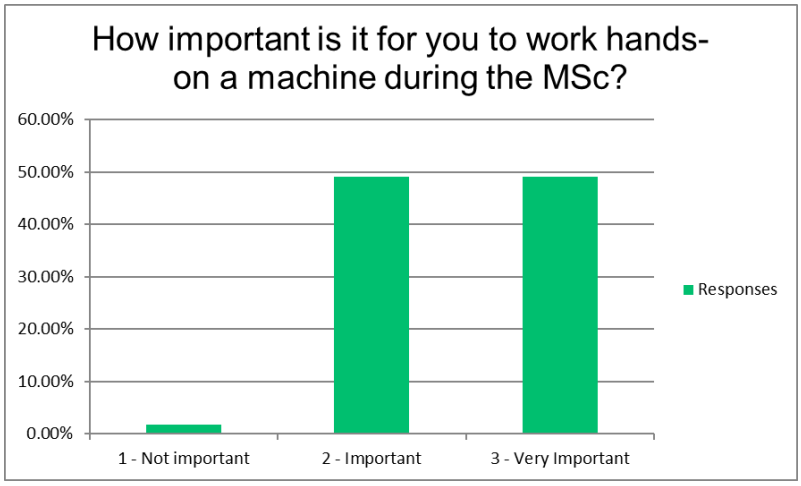

Figure 4 – Almost 100% of the student stakeholders stated that hands on access to AM machines during the degree course was important or very important.

Additional preferences were collected regarding what module structure prospective students would prefer. Table 3 shows that over 81% of the students would prefer general compulsory modules, with optional specialised modules in industrial sectors, materials or AM processes, whereas less than 19% would prefer to study only specialised modules in their curriculum. The preferred topic for specialisation is mainly industrial sectors (>37%), followed by Am processes (22%) or materials (17%). Finally, only 5.1% of the students would be interested by a specialisation in quality and inspection.

Table 4 takes this further by showing the relevance that prospective students placed on specific areas of the AM industrial space. All the prospective topics to be covered listed in Table 4, were considered to be relevant or very relevant by the majority of students, with AM process, design, structural integrity and metallurgical analysis and characterisation listed highest in priority.

Table 3 – Module structure that would most suit prospective students

	Responses
General compulsory core modules, followed by specific modules aimed at a specialisation in an industrial sector;	37.3%
General compulsory core modules, followed by a specialisation in specific AM processes;	22.0%
Modules applied to a specific industrial sector (e.g. aerospace) throughout the entire qualification;	18.6%
General compulsory core modules, followed by a specialisation in specific materials;	17.0%
General compulsory core modules, followed by a specialisation in quality and inspection;	5.1%
Other (please specify)	0.0%

Table 4 – How prospective students view the relevance of potential topics covering

	Not Relevant	Relevant	Very Relevant
AM processes	0.0%	26.8%	73.2%
Numerical Modelling	11.1%	57.4%	31.5%
Topology Optimisation	7.1%	55.4%	37.5%
Design	10.7%	42.9%	46.4%
Structural Integrity	0.0%	35.7%	64.3%
Metallurgical Analysis and Characteristics	3.6%	32.1%	64.3%
Post-Processing	1.8%	58.9%	39.3%
Pre-Processing and material handling	3.6%	67.9%	28.6%
Non-Destructive Testing	7.1%	62.5%	30.4%
Certification and Validation	19.6%	51.8%	28.6%
Testing / Quality Control	8.9%	58.9%	32.1%
Standards	10.9%	60.0%	29.1%
Costs	12.5%	60.7%	26.8%
Health and Safety & Environment	8.9%	67.9%	23.2%
Management / Business Administration	37.5%	53.6%	8.9%

Figure 5 clearly shows that there is a preference for individual dissertation style projects, whether these are classed as an industrial project or a thesis, otherwise a wide range of assessment methods is sought and therefore a balanced approach to assessment including an individual project is the preferred method of evaluation.

Further responses were gathered on what kind of supporting material and support services students would require, see Figure 6 and Table 5 respectively. These illustrate that students would like a range of supporting materials including tutorials, presentations, videos, handbooks and a database of materials data to aid their learning. For support services, the highest rated options were related to industrial links, with >78% wanting industrial experience and access to appropriate learning facilities (ca. 70%). An academic mentor and an industrial supervisor were also highly ranked (>60% and 59% respectively).

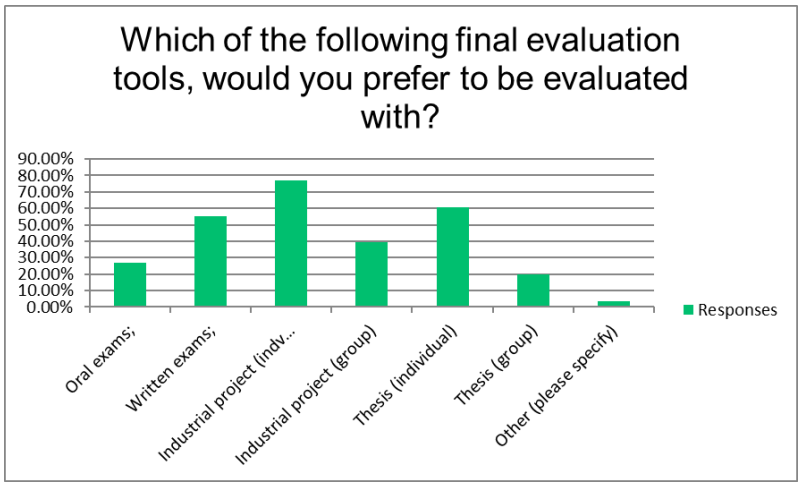

Figure 5 - Results illustrating that there is not a single preferred evaluation method with a wide range of evaluation methods required.

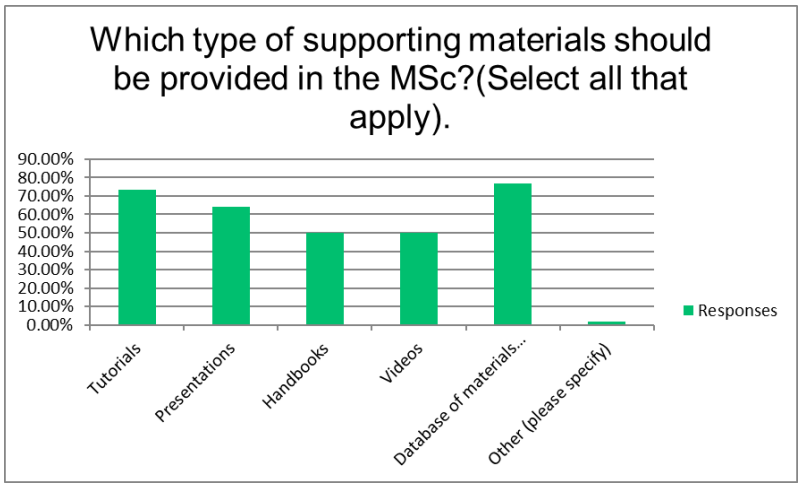

Figure 6 – The results show that the students would like a mixture of supporting materials throughout the course.

Table 5 – Responses for what type of support and opportunities students think should be provided

Answer Choices	Responses
Industrial experience;	78.6%
Wider support services and facilities (laboratories, IT system, library, administrative and social services);	69.6%
Have an academic mentor;	60.7%
Have an industrial coordinator/supervisor;	58.9%
Career counselling;	32.1%
Abroad experience;	26.8%
None.	0.00%
Other (please specify)	0.00%

Figure 7 illustrates that most responders wanted the course to be conducted full time, however a significant minority preferred intensive blocks or part time study. This is not surprising as it will depend on the circumstances of the individual, with university leavers likely to want to do a full-time master's and people currently in full time employment requiring more flexible methods of study, part time or intensive blocks, which can be fitted around current work commitments.

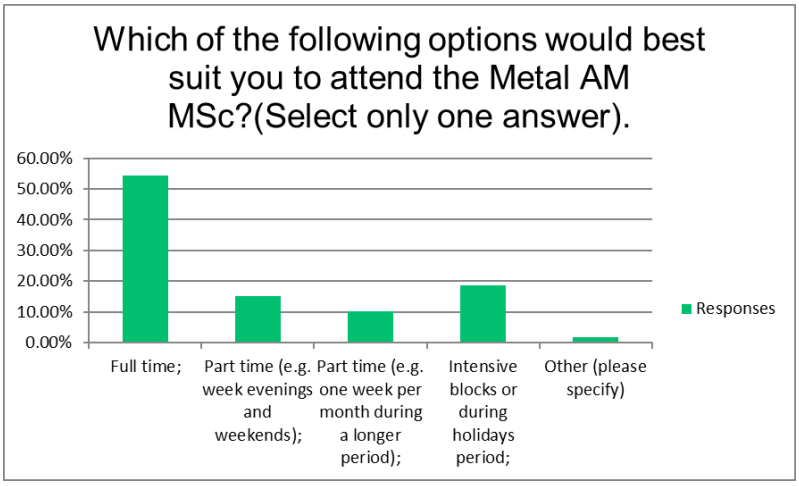

Figure 7 - Results from the student stakeholder questionnaire illustrating that the majority of people sampled would be interested in attending the course full-time.

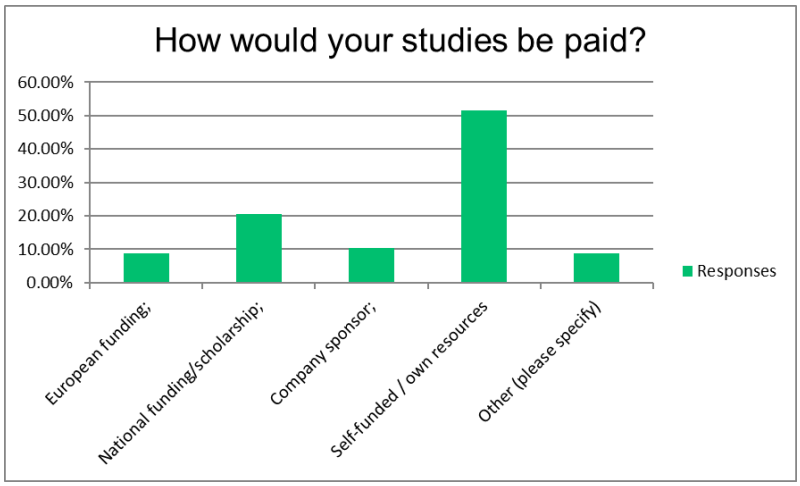

Figure 8 - Results from the student stakeholder questionnaire showing that the majority of respondees would expect to self-fund the course costs.

When considering how the course would be funded (Figure 8), the vast majority of students indicated that they would self-fund the expense, with minorities indicating that EU, national or company sponsorship would be used.

4.2 Industrial managers questionnaire

Two online questionnaires were produced to sample the opinions of industrial managers' stakeholder group to a MSc course in Metal AM. A number of questions were asked and these are included in the Appendix.

A total of 126 responses from the first survey and 88 from the second survey were collected from experts in the field and industry. A selection of the results to the surveys are included and discussed below. Figure 9 shows the type of organisations sampled for the questionnaire, illustrating the diverse range of AM related industries and stakeholders sampled.

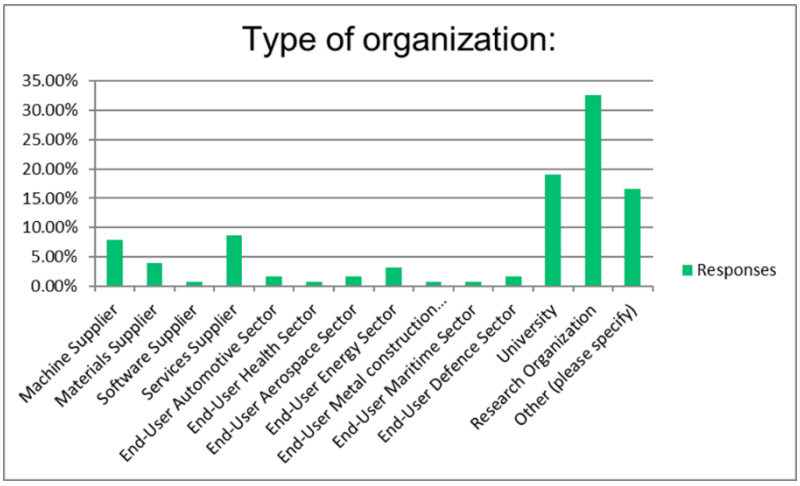

Figure 9 – Type of organisation for responders

4.2.1 Results

The feedback from the industrial managers' questionnaire was useful and discussed the topics and knowledge they felt a metal additive manufacturing engineer should have.

Table 6 – Responses for the training topics required for a qualification in metal additive manufacturing

Topics	Percentage
1. AM Processes	90%
2. Numerical Modelling	82%
3. Topology Optimisation	73%
4. Design	71%
5. Structural Integrity	85%
6. Metallurgical Analysis and Characteristics	87%
7. Post-Processing	76%
8. Pre-Processing and Material Handling	72%
9. Non-Destructive Testing	73%
10. Certification and Validation	68%
11. Testing/ QC	60%
12. Standards	80%
13. Costs	80%
14. HS&E	77%

80% of those sampled thought that the course should cover all AM processes and materials, with Table 6 illustrating the training topics that the course should cover, with all the listed topics very highly ranked according to the surveyed industrial managers in the AM sector. When comparing these results to those of the prospective students from Table 4 for which topics they thought were relevant or very relevant, the prospective students had similar responses in which topics they thought were important. However, they thought all topics were relevant or very relevant and in all cases the percentage of responses that thought this was higher than those recorded by industry experts.

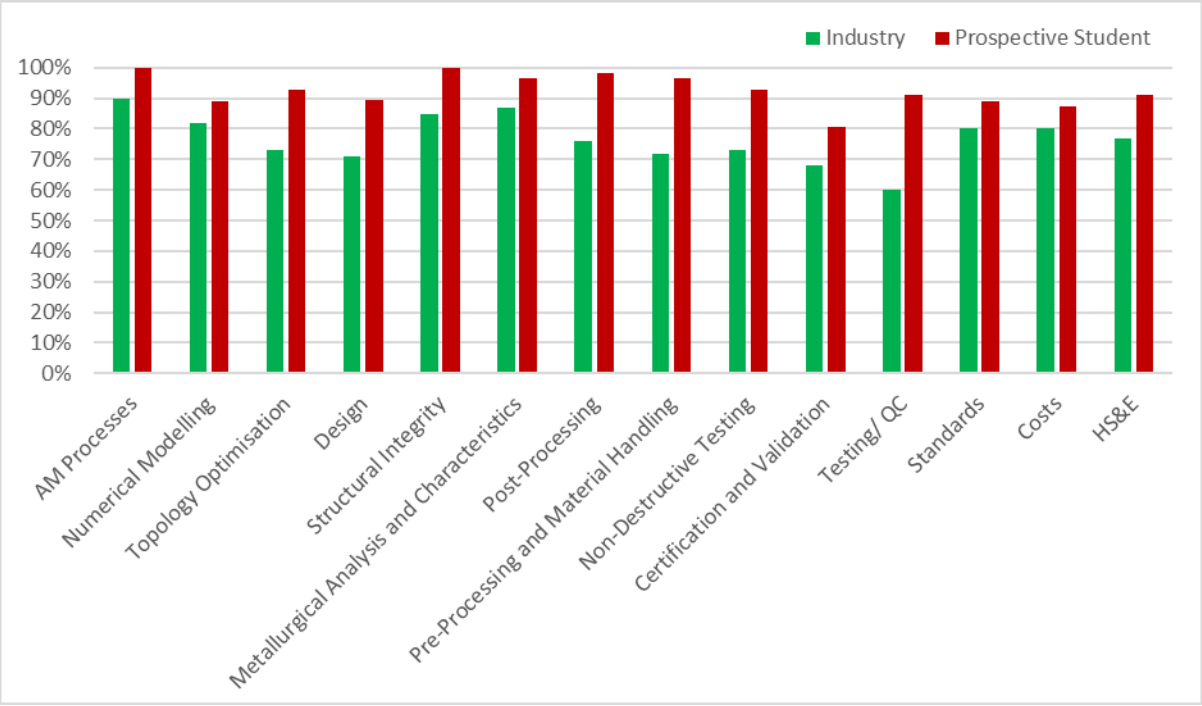

Figure 10 – Comparison of industry's perception of the training topics needed and what prospective students feel is relevant or very relevant to the course content.

Taking this further, the level of knowledge for each topic was considered on a scale of basic, intermediate and advanced (Table 7). The highest response for each topic is highlighted in red in Table 7 and shows that industrial managers would like to see advanced knowledge being developed in AM processes, post-processing and pre-processing and material handling. The rest of the topics were thought to require intermediate levels of knowledge and expertise. This was taken further to get a breakdown for the degree of theoretical and practical skills each topic should develop for the ideal metal additive manufacturing engineer. Half of the topics were expected to have a 50-50% split of theoretical knowledge and practical skill development (Table 8). There were also a number of topics that were considered to require 100% theoretical knowledge. Unsurprisingly, these were the topics where the tasks are desk based and regulatory: including HS&E, standards, certification and validation and cost.

Table 7 - The knowledge required for a metal additive manufacturing engineer

	Basic	Intermediate	Advanced
AM Processes	10.7%	15.4%	73.9%
Subtractive Processes	38.5%	46.2%	15.4%
Numerical Modelling	35.9%	51.6%	12.5%
Topology Optimisation	24.6%	46.2%	29.2%
Design	12.3%	44.6%	43.1%
Structural Integrity	18.5%	52.3%	29.2%
Metallurgical Analysis and Characteristics	21.5%	46.2%	32.3%
Post-Processing	15.4%	40.0%	44.6%
Pre-Processing and Material Handling	18.5%	40.0%	41.5%
Non-Destructive Testing	35.9%	45.3%	18.8%
Certification and Validation	33.9%	44.6%	21.5%
Testing/Quality Control	18.5%	56.9%	24.6%
Standards	29.2%	43.1%	27.7%
Costs	34.4%	39.1%	26.6%
Health, Safety & Environment	26.2%	40.0%	33.9%

Table 8 – Breakdown of the responses on how much practical/theoretical skills should be developed for a metal additive manufacturing engineering

	100% Theory	75%/25%	50%/50%	25%/75%	100% Practical
AM Processes	3.1%	20.0%	36.9%	33.9%	6.2%
Subtractive Processes	18.5%	40.0%	20.0%	20.0%	1.5%
Numerical Modelling	12.3%	40.0%	23.1%	23.1%	1.5%
Topology Optimisation	9.2%	29.2%	35.4%	23.1%	3.1%
Design	7.7%	18.5%	33.9%	30.8%	9.2%
Structural Integrity	12.3%	29.2%	40.0%	15.4%	3.1%
Metallurgical Analysis and Characteristics	14.1%	28.1%	37.5%	14.1%	6.3%
Post-Processing	4.6%	29.2%	21.5%	36.9%	7.7%
Pre-Processing and Material Handling	4.6%	27.7%	21.5%	40.0%	6.2%
Non-Destructive Testing	15.9%	31.8%	31.8%	14.3%	6.4%
Certification and Validation	37.5%	26.6%	25.0%	10.9%	0.0%
Testing/Quality Control	15.4%	33.9%	36.9%	10.8%	3.1%
Standards	41.5%	24.6%	20.0%	10.8%	3.1%
Costs	33.9%	30.8%	15.4%	13.9%	6.2%
Health, Safety & Environment	27.7%	26.2%	18.5%	20.0%	7.7%

5 Focus groups

A set of guidelines for facilitating the focus group was produced. Each focus group aimed to have a minimum of 3 people in it and a maximum of 10 and there was no fixed time for the focus group as a whole or for the discussion of an individual question. The person guiding the discussion used their discretion as to when to move on to the next question or bring the session to a close. The participants were also given an overview of the project before starting the discussion.

Four focus groups were held. The first one was held by ISEMP, University of Bremen for the higher education stakeholder group, the second one by University of Birmingham for the prospective student stakeholder group and the third and fourth at Cranfield University for the higher education stakeholder group and the industrial end-users stakeholder group. The transcripts for the focus groups are included in the Appendix.

5.1 Questions

A number of questions were provided to the focus group facilitator to choose from. The questions are based on those used during the recent student and industrial surveys as well as the results of those surveys and are listed below:

- Do you think there is a need for a new MSc in Metal Additive Manufacturing? The availability of skilled workers and availability of relevant training courses are two highest barriers to increased utilisation of AM, do you agree?
- What AM processes and materials do you think the course should cover? 80% of companies' staff surveyed thought it should cover all processes and all materials, do you agree?
- How much importance should be placed on practical skills and how much on theoretical skills? Is it important to have hands on experience of using AM machines?
- What aspects do you think the course should cover? How important are the following aspects:
    - AM Processes
    - Numerical Modelling
    - Topology Optimisation
    - Design
    - Structural Integrity
    - Metallurgical Analysis and Characteristics
    - Post-processing
    - Pre-processing and Material Handling
    - Non-destructive Testing
    - Certification and Validation
    - Testing/Quality Control
    - Standards
    - Costs
    - HS&E
- How should the course be studied? Full time, part time (one day a week), part time (intensive weeks), distance learning?
- Do you have an interest in attending such a course or sending your employees on such a course?

- Do you think the course should work closely with industry and contain industry sponsored projects?
- What sort of evaluation tools should be used? Written exams, oral exams, group projects, thesis or a combination of all/some?

5.2 Higher education feedback

ISEMP, University of Bremen held a focus group discussion with five persons from the Higher Education stakeholder group. This was conducted by Dr. Olga Zinovieva on Friday 15th December. In addition to this, Dr. Filomeno Martina had a number of discussions with staff at Cranfield University which are reported here.

The focus groups thought that there was a need for the course mirroring the results of both the industry and student survey. This was highlighted by the fact that all the AM individual projects on Cranfield University's other engineering master's courses are always popular and overbooked. Both groups also thought that all areas of the course should be covered in varying degrees of detail and that the students need to develop an understanding for all the aspects listed. Some of these could come as part of optional modules while others are covered in detail as core modules. As part of this, a significant amount of time needs to be spend developing practical skills.

The focus groups discussed options for how the course should be studied and those at the University of Bremen that all options were possible, but that the proposed method should be tested prior to full roll out to make sure it captures the intended number of students. They also noted that it would depend on the student, which is similar to the results of the survey that showed all methods were considered acceptable. In contrast, those at Cranfield University thought that we should continue with the current approach used there of full time over 12 months and part-time over 24 months with modules taken in week-long intensive blocks.

They both agreed with the survey results that the course should work closely with industry although noted it depends on the type of university the course is run at and thought that a mixture of theoretical projects and industrial relevant projects was necessary. The organisation of which, they noted, might be more difficult.

The feedback on evaluation methods mirrored that of the student survey in that a combination of assessment methods should be used. However, one important and additional point made was that universities generally already have an existing model of evaluation and it would make sense to follow these rather than create something new.

Finally, they stated that they would be happy to send their students on the course or to take students from the proposed course, which is positive. They also stated that if they were working in a company dealing with AM they would like to send some of their employees on the course.

5.3 Prospective student feedback

The Advanced Metals Processing Laboratory at the University of Birmingham held a focus group discussion with three final year undergraduate students from the School of Metallurgy and Materials. This was conducted by Dr. Sam Cruchley on Monday 8th January.

The underlining theme from the focus group was that the students agreed with the results from the questionnaire. They clearly agreed that the metal AM field is one which is current, interesting and expanding. They also thought that students would definitely be interested in

undertaking an MSc in metal AM as they felt that there is a drive for students to undertake more specialist degrees in order to help attain meaningful employment.

However, they did note that an increasing number of engineering students in the UK are now studying four year masters degrees and therefore may not want to study for another master's degree. Therefore there needs to be sufficient appeal for the new Metal AM MSc, and sufficient differentiation with a traditional Materials Science MEng/MSc.

In order to do so they thought that the course should include a mixture of theoretical and practical skills and be as applicable as possible to industry and the skills that industry require. To that aim, they expected the course to work closely with industry and be as industrially relevant as possible with industrially sponsored projects and assignments. They thought that the use of such collaborations during the course, including practical experience of using an AM machine, would benefit their future employment prospects.

The subject then moved on to methods of study and evaluation and the students again agreed with the survey results but expanded on some of the key points. They discussed and commented on different methods for studying, and thought that it depended on the background of the student and that we would need to assess this to get the best outcome of the students. Those that are going straight from a degree are likely to study full time, while those sponsored by a company are likely to want intensive weeks or part time study to allow them to continue working. They did also note that a distance learning option could be of benefit, especially for people living outside the country of study, which is likely to be particularly relevant in this case with a European MSc.

When moving on to evaluation tools, they thought a range of assessments should be used, but that a thesis from a practical assessment should contribute significantly to the overall grade for the course. Outside of that, they noted that while all students dislike group projects they are an important evaluation tool. However, they would like to see the addition of a lead academic that can guide the project and help with peer review, which was an interesting insight. They also thought that written exams were necessary and that a viva (or oral exam) would be useful.

Overall, the insights provided by the students are similar to those found with the student survey. However, their responses were extremely useful in clarifying and expanding on a few of the key points from the survey and provide a number of points to consider when designing the MSc course.

5.4 Industry end-user feedback

Dr Filomeno Martina had numerous discussions with industrial end users from Airbus, GKN, BAE systems, AWE and Meggitt over a period of three months. The results of these discussions are summarised here and are included in full in the Appendix.

The industrial end-users agreed strongly with the survey results throughout. In particular, they thought that this course was required, as recruiting people with the skill set this course would deliver is essential. It was especially noted that people with skills in WAAM were particularly hard to find. In addition, it was also stated that these companies would like to do more in-house research in AM but they need people with the right skills and background in order to be able to do so.

On the subject of course content, the end-users thought that the course needed to cover all processes at a basic level, with hands-on experience through a group project or thesis leading to a specialism in a particular topic would be ideal. On top of this, they thought that it was

important that the course covered modelling and simulation and quality control and design processes. Where there is a contrast with the results from students is that they thought that use of an AM machine is not imperative, as they are unlikely to be using the kit themselves when in industry. However, they will definitely need an appreciation of how AM machines work and what issues are likely to arise and how to fit them.

Interestingly, they also noted that a full time option could be very suitable for some of their employees on their graduate schemes, as the business does not require as much from them compared with traditional employees. They did note that being able to attend the modules as standalone course would be of some benefit and that part-time one-day-a-week would be very impractical for the company.

Unsurprisingly, they felt very strongly that the course should work very closely with industry to solve real world problems and give the students' experience of "real" projects, assuming confidentially can be ensured. This agrees well with the online surveys and what the students would like. On the subject of assessment methods, they agreed that a balanced approach was required, with group projects being particularly useful.

A number of other useful comments came out of the discussions, which included the need to work closely with machine suppliers, the importance of design optimisation including the ability to predict mechanical behaviour and considering how this fits into industry 4.0.

6 Summary of survey results

Overall, both the online survey and the focus groups undertaken have illustrated that there is a need and an interest in an MSc in Metal Additive Manufacturing. The results highlight a number of important aspects for the design of the course. These include the need for the course to have a significant industrial interaction throughout, with the course being tailored to the needs of industry. The use of industrially sponsored or relevant projects was another point considered important, as were the development of practical skills on an AM machine. However, on other aspects there was greater flexibility, for example, in terms of assessment methods everyone agreed that there is a need for a range of methods. Another important point was on the method of studying, with the student's background being the most important thing to consider.

7 Desk based research

This section describes a brief summary of the information gained from internet-based sources, including the scientific literature. The availability of skilled workers and of relevant training courses were frequently found to be the two highest barriers to increased utilisation of AM.

An extensive list of the barriers to increased utilisation and exploitation of the AM in industry have been identified [2]. These are listed below:

1. Availability of Education
2. Cost
3. Design
4. Software
5. Machine Constraints
6. In-process Monitoring
7. Materials
8. Mechanical Properties
9. Validation and Quality Control
10. Inspection and Finishing
11. Speed
12. Affordability

It has been noted through a study interviewing key stakeholders in the AM industry that each interviewee focused on their knowledge of a specific application or process and was mentioned that few people understand all the different methodologies and therefore the application of AM can depend on whether the right people with the right skill set are present [2].

Through these interviews it was established that, at present, most AM knowledge is filtered down from machine manufacturers, software developers and a small pool of experienced engineers, rather than through formal qualifications [2]. This is an inefficient process that results in an incomplete knowledge process. The paper then goes on to conclude that the knowledge of AM held by current engineering graduates is insufficient and a deeper understanding and experience of AM is required from these graduates.

AM is a quickly evolving field that has a range of application specific maturity levels and thus training is difficult to achieve effectively. Section 8 identifies the formal training courses which are currently available worldwide at a university level and will discuss these in more detail.

8 Current Additive Manufacturing Training Courses

This study has identified very few formal training courses that exist to specifically address metal additive manufacturing at a master's degree level. However, a few of MSc courses have been developed namely in the UK. These are listed in Table 9. All of these courses are designed to cover the whole additive manufacturing domain and include information of additive manufacturing of both polymers and metals. Further information on what these courses provide is included in section 8.1 and 8.2.

There are a number of short courses in additive manufacturing available, provided by Universities and other industrial bodies throughout Europe, which have not been detailed within in this report but are listed in Table 10 and Table 11 below. While these courses are useful by providing an insight into additive manufacturing they are far from the extensive training course in metal AM that industry craves.

Table 9 - Existing programmes at Postgraduate level

Course	Institution	Entry Requirements
MSc in Additive Manufacturing [13]	Anglia Ruskin University (UK)	Bachelor's degree: - Engineering/Maths/Science/Product Design/Related.
MSc in Additive manufacturing and 3D Printing [14]	University of Nottingham (UK)	Bachelor's degree: - Engineering /Science
MRes in Additive Manufacturing and Advanced Manufacturing Technologies [15]	University of Sheffield (UK)	Bachelor's degree or Relevant professional experience
MSc in Advanced Materials and Additive Manufacturing [16]	University of Derby (UK)	Bachelor's degree: - Chemistry/Biology/Geology/ Engineering/Subject related
2nd level Specializing Master in Additive Manufacturing [17]	Polytechnic University of Turin (IT)	Master's degree: - Engineering/Nanotechnologies for information and communications technology

Table 10 – Summer/Winter short course on AM

Course	Institution	Requirements
Summer School on Practical Robotics with 3D printing [18]	Tallinn University of Technology (EE)	- Engineers/Managers
Summer school course on Additive Manufacturing – 3D Printing [19]	Lappeenranta University of Technology (FIN)	- Bachelor's on their final year of studies; - Master Students in a technology or business field.
Summer school course on 3D Printing [20]	Aachen University of Applied Sciences (DE)	- Basic knowledge on manufacturing techniques and at least a CAD program.
European Summer University Additive Manufacturing [21]	Technical University of Dresden + Fraunhofer Institute for Manufacturing Technology and Advanced Materials (DE)	- Industry and Academia with no knowledge on the topic; - Outstanding bachelor or master students
Winter school on Introduction to 3D-Scanning and Printing [22]	Technical University of Berlin (DE)	
PhD summer school course on Design of Mechanical components using AM [23]	University Institute for Higher Studies, IUSS (IT)	- PhD students or young researchers
Summer school course on 3D Printing and Biofabrication [24]	Utrecht University (NL)	
Summer school course on 3D Printing [25]	Marbella Design Academy (ES)	- At least 1 year of university experience; - Basic knowledge of CAD software
Summer school Course on Design for Additive Manufacturing [26]	Lund University (SE)	- Engineers and designers; - Basic knowledge in CAD
EPMA Powder Metallurgy Summer School [27]	Location changing every year (Europe)	- Young scientists and engineers under 35 years old.

Table 11 – Short course and seminars on AM

Course	Institution	Requirements
Masterclass 'Design for additive manufacturing' [28]	Sirris (BE)	- Designers/Engineers/managers
3D Printing [29]	University of Southern Brittany (FR)	- Managers and technicians
Additive manufacturing production with Laser Metal Fusion [30]	Centre technique des industries de la fonderie (CTIF) & Spartacus3D (FR)	
Metal Additive Manufacturing [31]	Centre de formation de la plasturgie (FR)	
Metal-based additive manufacturing processes [32]	IREPA Laser (FR)	- Engineers/Researchers/Students
Design approaches for metal additive manufacturing [33]	CETIM (FR)	- Knowledge of AM materials and applications
Additive manufacturing, 3D printing - New technological issues and industrial perspectives [34]	École Polytechnique (FR)	- Engineers/Researchers/Project managers/Decision-makers
Certified Industrial Technician (IHK) - specialization in Additive Manufacturing [35]	SKZ + Würzburg- Schweinfurt Chamber of Industry and Commerce (DE)	- 5 years of professional experience; or - 90 ECTS in a technical university degree and one year of professional experience; or - Electrical engineer/ metal or mechatronics technicians or - Plastic technician with ≥1 year of experience
Master Additive Manufacturing: The Strategic Role of Metal Materials in Additive Manufacturing [36]	Rina Consulting + Politecnico of Milan and University Roma Tre (IT)	- Managers/Practitioners/researchers/ graduates/Students
Technician for Additive Manufacturing Project Managers [37]	TUCEP in cooperation with University of Perugia (IT)	- Managers/Executives/Recently graduates in Engineering or architecture.

Course	Institution	Requirements
Additive Manufacturing State of the Art [38]	Mikrocentrum (NL)	- Designers/Manufacturers/Product Engineers/Project leaders
Additive Manufacturing Lab Experience [39]	Mikrocentrum (NL)	- Designers/Manufacturers/Product Engineers/Project leaders
E-learning course on Technician for 3D printing [40]	CCC + King Juan Carlos University + TUmaker (ES)	
Fundamentals of 3D Digital Design & Additive Manufacturing [41]	Universidad Católica San Antonio de Murcia (ES)	
Master's in engineering and Additive Manufacturing [42]	EDDM (ES)	- Recently graduates engineers/ Engineers with work experience/ Entrepreneurs in technology
Continuing education course on Additive Manufacturing [43]	Zurich University of Applied Sciences (CH)	- Engineers/Architects/Scientists/ Technicians
Fundamentals of Selective Laser Melting (SLM) [44]	The Welding Institute (UK)	- Basic understanding of 3D printing
Short course on 3D Printing/Rapid Prototyping [45]	London Metropolitan University (UK)	
Advanced Introduction to AM-Practical training course [46]	The Manufacturing Technology Centre (UK)	- Decision-makers/Heads of engineering/Business owners
A Guide for Decision-Makers: Part 1-eLearning course [47]	The Manufacturing Technology Centre (UK)	- Decision-makers/Heads of engineering/Business owners
A Guide for Decision-Makers: Part 2-eLearning course [48]	The Manufacturing Technology Centre (UK)	- Decision-makers/Heads of engineering/Business owners
Technical Insight into AM-Ask the expert – virtual classroom [49]	The Manufacturing Technology Centre (UK)	- Decision-makers/Heads of engineering/Business owners
Design for Additive Manufacturing-Practical training course [50]	The Manufacturing Technology Centre (UK)	Bachelor's degree: - Mechanical Engineer/Product design/related subject

Course	Institution	Requirements
Design for Additive Manufacturing-eLearning course [51]	The Manufacturing Technology Centre (UK)	Bachelor's degree: - Mechanical Engineer/Product design/related subject
Technical Insight into Design for AM-Ask the expert – virtual classroom [52]	The Manufacturing Technology Centre (UK)	Bachelor's degree: - Mechanical Engineer/Product design/related subject
Practical Intro to the Full AM Process-Practical training course [53]	The Manufacturing Technology Centre (UK)	Bachelor's degree: - Mechanical Engineer/Product design/related subject
EPMA Metal AM Seminar [54]	Location changing every year (Europe)	- Scientists, engineers

8.1 Masters Courses Available in Additive Manufacturing – Europe

Currently there are three taught MSc courses and one research MSc(Res) course on Additive Manufacturing in the UK and one taught 2nd level masters in Italy. However, it appears there are no master's degree courses focussed on AM in Germany or Portugal. The MSc courses on Additive manufacturing are outlined in more detail below:

8.1.1 MSc in Additive Manufacturing at Anglia Ruskin University

Overview:
Claimed to be the 1st dedicated taught MSc in 3D printing and was developed in collaboration with Ford, Photocentric, IPECO, Selex Galileo and E2V.

It has received funding from HEFCE (the Higher Education Funding Council for England) under a pilot scheme to promote engineering and computer science conversion courses, with the aim of increasing the number of skilled graduates in the rapidly growing area that is Additive Manufacturing. The course is therefore open to people who have completed a range of undergraduate STEM degrees, as well as those with an engineering background.

The course aims to provide the students with the opportunity to design, develop and test engineering solutions in materials ranging from simple plastics through to high-end metal compounds using desktop and commercial 3D printers and direct metal laser sintering facilities. It will also involve the opportunity to carry out a project within a company to solve real-world manufacturing problems and deliver appropriate solutions.

Teaching load:
One year full time (2-3 days per week), two years part time (1 day per week)

Fees:
UK/EU full time - £8,100
International - £12,400

Entry requirements:

Minimum 2.2 in BSc or BEng in Engineering or Maths, Science or Product design based degree.

Modules:
3D CAD and Digital Techniques
Additive Manufacturing Strategy
Computer Aided Engineering Analysis
Innovative Product Design and Manufacture
Engineering Management Systems
Post Processing of Additive Manufactured (AM) products
Industrially Based Project

Assessment methods:
A variety of ways, including written assignments, portfolios, presentations, analysis reports and an industry based project.

8.1.2 MSc in Advanced Materials and Additive Manufacturing at the University of Derby

- Also available as a Postgraduate Certificate or Diploma.

Overview:
The course has been established with support from the Institute for Innovation in Sustainable Engineering (IISE) and with funding from HEFCE. It has been designed for both recent graduates and those in work, and is ideal for students who have undertaken study in other subjects who wish to start a career in manufacturing and other high tech industries.

The course combines advanced materials with additive manufacturing with the option of studying for a postgraduate certificate, diploma or master's degree.

Teaching load:
One year full time, two-three years part time

Fees:
UK/EU full time - £5,220
International - £12,240

Entry requirements:
A minimum of a 2:2 undergraduate degree or similar qualification in chemistry, biology, geology, engineering or a related analytical discipline and an A2 Mathematics or equivalent

Modules:
Introduction to Materials and Additive Manufacturing
Research Methods: Application and Evaluation
Environmental Risk and Responsibility
Additive Manufacturing Processes
Advanced Materials Science
Design and Materials Selection (optional)
CPD and Strategic Management
Additive Manufacturing Applications (optional)
Data Visualisation Science (optional)
Project

Assessment methods:
A variety of methods.

8.1.3 MSc(Res) in Additive Manufacturing and Advanced Manufacturing Technologies at the University of Sheffield.

Overview:
The course is aimed at both new graduates and professional mechanical engineers and has been reported to have been developed to meet the demands of industry. It is a research focussed master's degree (rather than mostly taught) which involves the majority of the assessment being based on an industry-focused research project on additive manufacturing. This research project is taken alongside a select number of specialist modules.

Teaching load:
Full time – One year

Fees:
UK/EU full time - £10,970
International - £20,470

Entry requirements:
Minimum 2:1 honours degree or equivalent in Mechanical Engineering or a related course

Modules:
Additive Manufacturing - Principles and Applications
Information skills for engineers
Research project

Design Innovation Toolbox (Optional)
Engineering Marketable Solutions: Make a Change (Optional)
Aerospace Metals (Optional)
Advanced Materials Manufacturing Part 1 (Optional)
Engineering Composite Materials (Optional)
Condition Monitoring (Optional)
Advanced Topics in Machining (Optional)

Assessment methods:
A variety of methods.

8.1.4 MSc in Additive Manufacturing and 3D printing at the University of Nottingham.

Overview:
The course is aimed to provide the advanced skills and knowledge in additive manufacturing and 3d printing required to become an industry professional or research in this area.

Teaching load:
Full time – One year

Fees:
UK/EU full time - £7,290

International - £21,285

Entry requirements:
Upper second class hons Bachelor of Engineering (BEng) or Bachelor of Science (BSc) first degree or international equivalent. Applicants with qualifications below the minimum may be considered if they have relevant industrial experience (e.g. research and development environment) of at least 5 years, subject to approval by the Quality and Standards Committee. CELE pre-sessional course final assessment of "Pass with Merit"

Modules:
Group Grand Challenge
Introduction to Additive Manufacturing
Advanced Engineering Research Project Organisation and Design
Advanced Additive Manufacturing
Introduction to Metrology
Advanced Materials
Individual Postgraduate Project
An additional 10 credit core module (to be confirmed)

Assessment methods:
A variety of methods.

8.1.5 2nd level specialising Masters in Additive Manufacturing at the Polytechnic University of Turin.

Overview:
The objective of the Master Course is that of training young and motivated, newly-graduated engineers in order to create a new generation of high-level specialists in the Additive manufacturing process field.

Teaching load:
Full time – Two years

Fees:
Free for selected students. Partner companies will offer a job under a higher apprenticeship contract.

Entry requirements:
Must hold a full MSc in one of the following:

- Aerospace Engineering
- Automotive Engineering
- Computer Engineering
- Electrical Engineering
- Electronic Engineering
- Industrial Production and Technological Innovation Engineering
- Management Engineering
- Materials Engineering
- Mechanical Engineering
- Mechatronic Engineering
- Nanotechnologies for ICT

In addition must be under the age of 30 at the start of the course.

Modules:

- Design for Additive Manufacturing
- Materials for Additive Manufacturing
- Additive Manufacturing systems
- Advanced sensors for the control of Additive Manufacturing systems
- Integration of Additive Manufacturing technologies with conventional processes for parts' finishing
- Systems for the evaluation of products made using Additive Manufacturing
- Production management in Additive Manufacturing systems
- Supply chain management in Additive Manufacturing systems
- ICT platforms for facilitating the integration of Additive Manufacturing in traditional manufacturing processes
- Managerial training processes
- Training on the job and individual project work

Assessment methods:
A variety of methods.

8.2 Masters Courses Available in Additive Manufacturing – Outside Europe

Currently there is only one taught MSc courses on Additive Manufacturing outside Europe; within the United States of America. The course is outlined in more detail below;

8.2.1 MSc in Additive Manufacturing and Design at Penn State University in the USA

Overview:
Penn State University claims to offer the first exclusive master's degree course on Additive Manufacturing starting in autumn 2017. It is a cross-departmental master's course which has involvement from the Mechanical and Nuclear Engineering, Industrial and Manufacturing Engineering, Engineering Science and Mechanics, School of Engineering Design, Technology, and Professional Programs, and Materials Science and Engineering departments. The program aims are to prepare students to:

- Apply foundational knowledge, critical thinking, problem solving, and creativity in the uses of additive manufacturing and associated design tools and methods.
- Grow as leaders in manufacturing while maintaining the highest ethical standards in applying additive manufacturing to industry-relevant problems and design challenges.
- Strive for the advancement of the state-of-art in additive manufacturing and design.
- Develop innovative solutions through new design paradigms in their respective industries.

Teaching load:
Full time – One year

Fees:
$13,200 per semester + $252 information technology fee

Entry requirements:
Applicants must hold a Bachelor of Science or four-year Associate's degree from an accredited institution in engineering, engineering technology, manufacturing, materials science, or related field.

Modules:
Design for Additive Manufacturing
Scientific and Engineering Foundations of Additive Manufacturing
Additive Manufacturing Processes
Additive Manufacturing of Metallic Materials
Metal Additive Manufacturing Lab
Research project

Two elective modules which can be in design, materials, manufacturing, technical writing, technical presentations or supply chain.

One non assessed seminar course

Assessment methods:
A variety of methods

8.3 Summary of Current Training Courses Available

There are currently no courses, which focus solely on metal AM with the current available courses dedicating significant amounts of time to all materials. Metal AM has potentially the greatest need to allow industry to fully exploit the technological advantages it provides.

Clearly, while there are a significant number of short courses available within Europe there is a significant limitation in what formal training courses are available at Master's level to address the educational deficit in metal AM. Definitely no courses tackle the topic of large-scale metal AM. As a result, there is the need and space for a further well-developed AM master's degree, which has the option of being run part time and full time. While a couple of limited programmes are being run already within the UK, one in Italy and another one in the USA, these do not meet the current demand for people with the right skill set as highlighted by the results provided in this report. Therefore there is a very strong demand for the course the ADMIRE consortium wishes to establish as a result of the investigation presented in this report.

9 Summary and Conclusions

Enhancing the collaboration between universities and the industry at large is of paramount importance in general but is especially important in additive manufacturing. AM is a rapidly growing production method with clear advantages in terms of efficiency, flexibility and even from an environmental perspective. The increasingly complex nature of AM products and production processes necessitate a highly qualified workforce with a new skill set. The availability of employees with this highly specialised skill set has been clearly identified as limited.

This report has reviewed and analysed the state of the AM industry as well as the needs of the key stakeholders in regards to the creation of an executive joint MSc in Metal Additive Manufacturing. The results from the online surveys and focus groups targeted at these key stakeholders, have clearly identified a cohort of people interested in this proposed master's course. It has recognised that an increasingly joined up collaboration between both academia and industry in designing a comprehensive curriculum for a suitable metal AM course is required to address the lack of suitable training courses. Furthermore, the feedback collected has highlighted particular areas of the course syllabus and structure that are considered important to the success of the course.

Finally, while the report has identified that there is a significant number of short course on AM available within Europe there are currently no masters level courses which focus solely on Metal AM, to address the education deficit within industry. There is therefore a need for a well-developed, industrially relevant master's course in metal additive manufacturing.

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11 Appendix 1 – Focus group transcripts

Transcript for Higher Education Focus group

Introduction

ISEMP, University of Bremen held a focus group discussion with five persons from the stakeholder group Higher Education on 15th of December. The person guiding the discussion is Dr. Olga Zinovieva.

Higher education and research staff perspectives

Included below is a list of guiding questions. These are by no means exhausting and the host is advised to use their knowledge and discretion to ask further or different questions to get the most out of the groups.

Question asked during focus group

> Do you think there is a need for a new MSc in Metal Additive Manufacturing? The availability of skilled workers and availability of relevant training courses are the two highest barriers to increased utilisation of AM, do you agree?

Findings from the focus group

> First, we need to understand what type of specialist a student will be after graduation. He can work with AM machines, AM software. The student will know everything about the process chain, different technologies and machines, different software and how he can use it.
>
> Yes, there is a need for a new MSc in Metal AM. Currently, the problem with existing courses is that most of them teach you to think in subtractive way to manufacture things. The 'vision' to work in additive manner should be developed. Students should learn the process chain, materials used in AM, what happens to the materials, which software to use.
>
> It is very necessary. Right now, it is pretty difficult to find all this information because it is new, and you should search for it in different sources, not even in books. You need to work with it in order to understand it.
>
> The current alternative is just to hire people and train them. With the current availability of relevant training courses, you cannot even properly train them.
>
> An interesting question is: should it be a Master course in a regular university or in a university of applied science, where you go to the machines, and learn with the machines? In the normal university, I am not sure whether a student will go to the machines, and learn how to use them.
>
> It would be great to include a practical semester inside the MSc Programme – about 3-4 months when students are inside a company and really in front of machines.
>
> The question is: is it necessary to have a course solely for this technology or is it a good idea to vary already existing MSc Programmes like Manufacturing Technology?

It would be interesting as well to have some theoretical courses included in the MSc Programme, for example, some physics courses, depending on what a person is interested in.

We could ask ourselves which person we would like to have in order to work on a project. Should this person have a degree in Metal Additive Manufacturing? Depends on the project. Good mixture of people will be the best decision.

Question asked during focus group

What AM processes and materials do you think the course should cover? 80% of companies staff surveyed thought it should cover all processes and all materials, do you agree?

Findings from the focus group

There should be one special subject introducing a little bit of AM history, all technologies, and currently used technologies.

There could be one course being an introduction to the AM process in general. The theoretical course organized as follows: these AM processes are available, their applications, a process chain. I had such a course at a university where I studied. A number of processes were introduced, without any mathematics and physics, just how the process works and where it can be applied.

This totally makes sense to have a course with a general overview of different AM processes and materials. This course should not go into detail. Then you can have different courses and let students choose some of them where they can specialise in the AM technique they are interested in.

It is definitely necessary to have a broad overview to start with. Or maybe you can start with something specialised, so students can understand what this process is about. Then you can give an overview, and the students can better understand what the difference between processes is. You can start with the laser powder-bed process, explain it in detail, and then give an overview, what else is there in metal AM. Probably like that it would be easier to understand what the differences are.

You can start with a basic process chain containing all technologies, and then provide this process chain in more detail for each AM process.

Concerning materials, many alloys are possible to be created for metal AM. The course should cover the currently used metals like titanium, steel, aluminium, copper.

It would be interesting to create a course about the development of new alloys for metal AM. It is a very important and challenging topic, and many people work on it. At least it should be the theory how and based on what people develop new materials for metal AM, what possibilities they have. Something like “Alloy Development for Metal AM”.

Students should also know what strategies/other parameters one can use to change the behaviour of additively manufactured material.

Question asked during focus group

How much importance should be placed on practical skills and how much on theoretical skills? Is it important to have hands on experience of using AM machines?

Findings from the focus group

The second part of the question was already answered. You should have hands on machines. I think you should start in a theoretical way, provide students with an idea what is happening. I would say about 60% of theory and 40% of practice – using AM machines, removing support structures, getting a feeling about how support structures work, how your laser works with powder, etc.

The question is what these people will do later. Maybe it is their more or less sole opportunity to really touch the process. It is really important that students have an idea what is going on.

It would be interesting if they have an introduction to technologies (20% of theory), then practical experience (40% of practice), and last 40% of the theory with already more deep understanding.

Suppose you have your main courses and then electives. You can organize, for example, three groups of electives where one can go for numerical modelling, one can go for metallurgy and materials science (characterization, experiments), one can go for business models. Students can choose electives up to them but they need to have a core understanding of the metal AM.

Question asked during focus group

What aspects do you think the course should cover? How important are the following aspects:

a. AM Processes
b. Numerical Modelling
c. Topology Optimisation
d. Design
e. Structural Integrity
f. Metallurgical Analysis and Characteristics
g. Post-Processing
h. Pre-Processing and Material Handling
i. Non-Destructive Testing
j. Certification and Validation
k. Testing / Quality Control
l. Standards
m. Costs
n. HS&E

Findings from the focus group

If it is an MSc in Metal AM, it should cover everything. Not everything in detail, but every aspect here is important, and students have to know something about every aspect.

All aspects should be in the course, at least in the introductory manner.

Certification stuff, Standards, Costs are not the core process. They could be courses of choice.

You will have people that would like to be in leader positions later. They need to know more about economics standpoint. But I do not think it should be a focus because MSc Programme does not have so much time.

I think students need to know about basics of everything here. At some point, they need to go into detail about a particular topic they choose. AM Processes aspect is a must. Numerical Modelling: you need basics but if you are interested, then you can do a course of choice. Topology Optimisation is the same as Numerical Modelling in terms of importance. Design is more important, it should be a must-do course.

Structural Integrity is that your part does not fall apart after you build it so it is important.

Metallurgical Analysis and Characteristics is very important. It should be kind of basics in the first semester. Post- and Pre-Processing both are very important if you want to be an MSc of Metal AM. It could be an introductory course, and also an advanced course as well.

I think it should be an advanced course.

Non-Destructive Testing can be elective. If you are interested, you can choose it, if not, just give your part to other technicians, and they test it for you. Certification and Validation aspect is good to know if you are interested, otherwise, it is boring.

Most of the topics should be at least shortly addressed in an introductory course. Then you need to deepen the knowledge on topics you choose.

HS&E is important as well. For example, for handling with powders it is necessary that you had at least some kind of introductory course on HS&E before you go to the lab for practice.

In numerical modelling, you can divide models and methods by scale: macro-, meso-, and microscale, – and give students an overview of them by scale. Maybe it can be a course how to use the already existing software.

Anyhow, they need to have an understanding what the heat transfer, metallurgical aspects, solidification, continuum mechanics etc. are about. All that should be a part of the first semester.

Question asked during focus group

How should the course be studied? Full time, part time (one day a week), part time (intensive weeks), distance learning?

Findings from the focus group

It strongly depends on a student. There are people who are really good at learning when visiting lectures. There are people who are really good at learning when they have a script. This is a distinct point between full-time course and distance learning. For the labs, you have to be there. I think it also can be a course you can do parallel to your work. In this case, you would like a part-time course but then it should take more than two years.

If you introduce your course for the first time as a full-time course and there are no students, so you will have losses. I would suggest to test it for other types of courses (part-time or distance learning) and check how people respond. If they have a lot of interest, next time the course can be organized as a full-time course. It depends on the business model of the course. Whether you want to take a risk and introduce the course as a full-time one or you have all the data, know the student response and what to change if you need to, and then introduce the course as a full time one. In my opinion, it is more about the commercial decision.

I think, full-time course, definitely. Distance learning should be a possibility as well. If you want to go in new ways of teaching it could be interesting to have videos of lectures, so students could watch them afterward again. If you have a video, you can always look up what a professor said about a certain topic. If you have it in writing, it can just be gone. It could also be a good feedback for a professor, so he could watch himself and see what can be changed.

Question asked during focus group

Do you have an interest in attending such a course or sending your employees on such a course?

Findings from the focus group

We could send our students on such a course.

Yes, or take students from there.

If I worked in a company dealing with AM, I would really like to have any of my employees attending such a course or to get people who attended this course. It would really be nice to have a person who has been dealing with Metal AM very intensely during last two years. I think, yes, I would be interested in getting people coming from this MSc.

Many of us here work on metal AM but we did not attended any MSc course. We are still working on AM. That is an interesting point. It emphasizes the importance of fundamental courses. It will be important to bring people to the same background. You have to think what the common background of your students should be and what is necessary for them in order to understand the subjects you want to teach them.

I would have been happy to invest the time I invested in atomistic simulations during my MSc into working with an AM machine or learning about Design and Topology Optimisation.

Question asked during focus group

Do you think the course should work closely with industry and contain industry sponsored projects?

Findings from the focus group

It could work closely with industry. I would say it depends on a type of university where the course takes place – a classical university or a university of applied science. If you are doing your course at the university of applied science, there should be definitely some projects you are doing together with the industry. If it is a regular university, there could be such projects.

I guess it depends on a university. For your MSc, you can either work closely with a company or do more theoretical stuff in a university. Both opportunities should be available. I think it is always a good idea to have a mixed approach when you are part-time in a university and part-time in a company. The question is about organizing it.

Question asked during focus group

What sort of evaluation tools should be used? Written exams, Oral exams, group projects, thesis or a combination of all/some?

Findings from the focus group

A combination.

I think universities have already existing models of evaluation. It is better to use something that already exists.

The thesis should be at the end of MSc. Some group projects are always nice. Concerning written or oral exams, it depends on how many students you have.

With multiple choice tests you can always say whether a person is good or bad in the subject. Oral exams: some persons are effective in that, some are not.

There should be a mixture of different testing styles. There can be some kind of oral exams for practical lessons. There can be written exams containing multiple choice tests for lectures. Concerning group projects, I can imagine when you are at the end of your Master course and already choose your orientation for your Master thesis, you can make some two-three-four student groups for a project to develop something. Based on that, you can do one or two person Master thesis.

Transcript for Prospective Students Focus group

Introduction

The Advanced Materials Processing Laboratory at the University of Birmingham held a focus group discussion with three persons from the stakeholder group undergraduate students (final year students) on 8th of January 2018. The person guiding the discussion is Dr. Sam Cruchley.

Prospective Undergraduate students

Included below is a list of guiding questions. These are by no means exhaustive and the host is advised to use their knowledge and discretion to ask further or different questions to get the most out of the groups.

Question asked during focus group

> Do you think there is a need for a new MSc in Metal Additive Manufacturing? The availability of skilled workers and availability of relevant training courses are the two highest barriers to increased utilisation of AM, do you agree?

Findings from the focus group

> Yes, the area is very current, interesting and is expanding. Students would definitely be interested in doing it as it gives them an expertise in a new expanding area. As degree fees have increased, we are increasingly looking for ways to differentiate ourselves and to get value for money. This is leading to a drive for us to undertake more specialised degrees, as this seems to be more important with getting employment after university.
>
> How would it differ from a regular MSc in say Materials Science, which already covers modules on AM? It would need to be different enough to differentiate itself from the traditional materials masters courses.
>
> It is definitely needed however it may not be useful for MEng students who currently undertake 4 year degrees. Could this MSc maybe feed into the final year of a MEng leading to a specialism in Additive Manufacturing?

Question asked during focus group

What AM processes and materials do you think the course should cover? 80% of companies staff surveyed thought it should cover all processes and all materials, do you agree?

Findings from the focus group

I think that the course should cover everything that industry require, and be specific to the processes and materials that are going to be most useful in an AM career in the UK/Europe. While it be great if all AM processes could be covered in detail, is it feasible to cover all materials? It would be good if the course could cover a detailed overview of all the processes and a large number of applicable materials with the option of taking elective modules which allow you to specialise in one machine type or in a small material class or both.

It needs to be as applicable as possible to industry and the skills they require.

Question asked during focus group

How much importance should be placed on practical skills and how much on theoretical skills? Is it important to have hands on experience of using AM machines?

Findings from the focus group

A good mixture of theory and practical skills is needed. The practical skills are extremely important as this provides valuable skills to put on your CV. The emphasis should be placed on practical skills that industry (or academia) might value.

Another factor may be what student background you expect, as you could get a very mixed level of background knowledge and prior skills. Therefore the underpinning theoretical knowledge needs to be there before moving on to specific practical skills and hands on use of AM machines.

The use of AM machines is very important but by no means essential. However, there would be an expectation from the students that they at least get use of one machine. Going further practical knowledge of the full range of machines would be very useful and an advantage but equally not essential (or realistic).

It might also be a good idea to include business modules as specialised elective modules that students could choose to take.

Question asked during focus group

How should the course be studied? Full time, part time (one day a week), part time (intensive weeks), distance learning?

Findings from the focus group

The course could be studied in any number of ways effectively and would depend on where the student was coming from as to what would be most useful. A student coming straight from a BSc in something like Materials Science would likely want to complete the degree in a full time capacity in something similar to the way a full time undergraduate degree is studied.

However, if the student was sponsored by a company in industry then they are likely to want to keep their job while doing it, and the company is likely to only want to release the student one day a week or for intensive weeks. I think intensive weeks would be better for me as it would be easier than having one day out the office every week.

The distance learning option would have huge benefits for both workers in companies and people who might not be able to take the time off or live in countries outside where the course is being held. Overall we think that you need to assess the background of the students you want to do the course, and choose the appropriate method or offer a range of methods for different student types.

Question asked during focus group

Do you think the course should work closely with industry and contain industry sponsored projects?

Findings from the focus group

I think we have already implied that working closely with industry is extremely important and that the course should be industrially relevant. The ability to work closely with industry on industry sponsored projects would be of benefit to students not currently in employment as it helps them get a foot through the door at a company and maybe of which could lead to employment.

However, I think it is important to have a range of projects some industrially sponsored, some academically inclined which could have the potential to lead onto a PhD.

I assume any sponsored students would undertake an industry project supplied by their company. As this would probably make the course more attractive to both the student and the employer.

Question asked during focus group

What sort of evaluation tools should be used? Written exams, oral exams, group projects, thesis or a combination of all/some?

Findings from the focus group

An interesting question, firstly there has to be a thesis which contributes heavily to the overall grade. This needs to be an individual project which involves independent research whether sponsored by a company or not and must involve practical skills (machine or modelling etc).

Even though no student likes group projects they are important and need to be included but in order to make them more effective they should be of a reasonable size and have a lead academic to guide the project and help with peer review (i.e. help people pull their weight). One way that works is to get the lead academic to get each person in the group to present what they have done on a two-three week basis. This seems to get the students to engage in doing work regularly as they don't want to look silly in front of the class by presenting nothing.

Written exams are obviously an important aspect which should be kept and these should include a mixture of short answer questions and essay based questions and maybe some multiple choice but these might be too easy for a master level course.

Oral exams are not something I had thought about, however having a viva is an extremely useful way of preparing for an interview so is something that is useful. You do need an academic that cares otherwise it is not always helpful or useful.

I feel that the course should include a range of assessments. I agree but you also need to consider the background and culture of the students, especially in group based work to make sure it is valuable and a useful way to assess people. Could you give the option for the students to place value on each type of assessment so they can focus on ones they perceive they are better at and put less weight on the ones they struggle with?

Question asked during focus group

Do you have an interest in attending such a course or sending your employees on such a course?

Findings from the focus group

Potentially, however I would need more information on the future direction of the course and the industry. I would definitely be interested in being sent by the company I work for. Similarly for me, I am still considering my options but don't think I am going to go into the AM field and therefore it would not be for me. However, I can see why people would want to do it as it is an interesting and developing field.

Transcript for Industrial End-users Focus group

Introduction

The content of this report covers discussions had with industrial end-users at the end of business meetings, over the course of three months. The person guiding the discussion was Dr Filomeno Martina. The representatives belonged to Airbus, GKN, BAE Systems, AWE and Meggitt.

Industrial end-users

Included below is a list of guiding questions. These are by no means exhaustive and the host is advised to use their knowledge and discretion to ask further or different questions to get the most out of the groups.

Question asked during focus group

> Do you think there is a need for a new MSc in Metal Additive Manufacturing? The availability of skilled workers and availability of relevant training courses are the two highest barriers to increased utilisation of AM, do you agree?

Findings from the focus group

- Recruiting people with these skills is definitely needed
- Uptake/industrialisation of WAAM, and currently there is absolutely no way to find someone with background/experience in materials, robotics, and processing
- Great evidence of AM's potential, would like to do more research in-house to promote industrialisation but people with the right background are needed
- Great avenue for L7 apprenticeships if possible

Question asked during focus group

> What AM processes and materials do you think the course should cover? 80% of companies staff surveyed thought it should cover all processes and all materials, do you agree?

Findings from the focus group

- At a basic level it should cover all processes. Hands-on experience – group projects – thesis good means to promote specialisation in a particular topic (including modelling)
- Plastics and metals are important equally, however in light of the background of the institutions involved, all doing great research in metals, these should have the priority
- Value chain is key – not just manufacturing but also quality and design
- Modelling and simulation is also extremely important
- The course should be technically rich

Question asked during focus group

How much importance should be placed on practical skills and how much on theoretical skills? Is it important to have hands on experience of using AM machines?

Findings from the focus group

- The future employees might not be using the kit themselves but need to know the issues and how to solve them
- They might be training and supporting technicians so some knowledge of machines is needed

Question asked during focus group

How should the course be studied? Full time, part time (one day a week), part time (intensive weeks), distance learning?

Findings from the focus group

- Interested not only in the board PT/FT option but also in the possibility of taking modules individually (as short courses)
- Part time (one day a week) very impractical
- The more distance learning, the better – companies don't like to lose key staff for long periods
- Indeed a FT option might be also suitable for young employees enrolled in graduate scheme, as the business does not need them as much as mature employees

Question asked during focus group

Do you have an interest in attending such a course or sending your employees on such course?

Findings from the focus group

- Yes to have an in-house expert on the subject

Question asked during focus group

Do you think the course should work closely with industry and contain industry sponsored projects?

Findings from the focus group

- Definitely – also interested in using real problems provided confidentiality is ensured
- Yes – the more "real" the projects the better

Question asked during focus group

What sort of evaluation tools should be used? Written exams, oral exams, group projects, thesis or a combination of all/some?

Findings from the focus group

- Written for theoretical subjects. Hands-on / PBL / case studies for practical aspects
- Thesis needed for specialisation
- Group projects are good to learn about team-work and addressing issues together under pressure

Other comments emerging from the discussion:

- Need to work closely with equipment suppliers
- Need to consider Industry 4.0 as much as possible
- Massive role of design optimisation, therefore ability to predict mechanical behaviour offline is fundamental
- Having one person who can think with AM in mind seems to be important to enable radical shifts in paradigm within the companies

Transcript for Academic Teaching Staff Focus group

Introduction

The content of this report covers discussions had with academic and teaching staff over the course of four months. The person guiding the discussion was Dr Filomeno Martina. The representatives belonged to the current Cranfield University staff.

Academic and teaching staff

Included below is a list of guiding questions. These are by no means exhaustive and the host is advised to use their knowledge and discretion to ask further or different questions to get the most out of the groups.

Question asked during focus group

> Do you think there is a need for a new MSc in Metal Additive Manufacturing? The availability of skilled workers and availability of relevant training courses are the two highest barriers to increased utilisation of AM, do you agree?

Findings from the focus group

- Yes, as a growing interest is seen in new students and the AM projects are usually overbooked

Question asked during focus group

> What AM processes and materials do you think the course should cover? 80% of companies staff surveyed thought it should cover all processes and all materials, do you agree?

Findings from the focus group

- We have enough expertise in all these subjects and are ready to teach accordingly to the results of the needs analysis

Question asked during focus group

How much importance should be placed on practical skills and how much on theoretical skills? Is it important to have hands on experience of using AM machines?

Findings from the focus group

- At Cranfield a lot of our Materials students prefer working in the laboratory as opposed to their desk and this type of students will want to be on the machines
- Not necessarily because some candidates will want to be proficient in modelling and engineering design

Question asked during focus group

How should the course be studied? Full time, part time (one day a week), part time (intensive weeks), distance learning?

Findings from the focus group

- We would like to continue with the current approach, FT for 12 months and PT over two years with week-long blocks.

Question asked during focus group

Do you think the course should work closely with industry and contain industry sponsored projects?

Findings from the focus group

- Yes this is fundamental
- Yes however sometime our students work on original research ideas which do not have a sponsor yet.

Question asked during focus group

What sort of evaluation tools should be used? Written exams, oral exams, group projects, thesis or a combination of all/some?

Findings from the focus group

- We are moving away from written exams but these are probably useful for the foundation modules (metallurgy etc)
- Oral exams – no
- GPs, theses, assignements are very useful

Other comments emerging from the discussion:

- Need to minimise the amount of new modules developed right off the bat

- Could include the new MSc in a portfolio of “Manufacturing MSc” with shared cored modules and different options f.i. Metal AM, Composites, Precision casting etc

12 Appendix 2 – Questionnaire

Questions asked student questionnaire

- Have you got any work experience?
- How many years of work experience do you have and in which fields?
  - Numerical Modelling
  - Design
  - Inspection
  - Robotised Systems
  - Materials Science
  - Welding and Allied Processes
  - Machining and Other Manufacturing Processes
  - Additive Manufacturing
- Are you currently employed?
- If yes, does your employer already use 3D printing?
- If yes, in which material?
- Would your company give you access to its resources (equipment and AM machines) for work development in the MSc?
- Do you already have experience on an AM machine?
- If yes, in which material?
- Would you have interest in attending a Metal Additive Manufacturing master degree?
- Why do you have interest in doing a Master degree in Metal Additive Manufacturing? (Select all that apply)
  - It's a new subject/topic
  - Possibility to get a specialisation in this technology
  - Possibility to learn new processes
  - There's a positive growth and uptake of AM technology in the European and International market
  - Would like to work in AM technology in the future
  - Other (Please Specify)
- How would your studies be paid?
  - European funding
  - National funding/scholarship
  - Company sponsor
  - Self-funded / own resources
- How would you rate your metal material science skills?
  - Poor
  - Fair
  - Good
  - Excellent
- How would you rate your design/CAD skills?
  - Poor

  - Fair
  - Good
  - Excellent

- Which of the following options would best suit you to attend the Metal AM MSc? (Select only one answer)
  - Full time
  - Part time (e.g. week evenings and weekends)
  - Part time (e.g. one week per month during a longer period)
  - Intensive blocks or during holidays period

- Please choose the option that would suit you the most. The MSc degree in Metal AM should address:
  - Modules applied to a specific industrial sector (e.g. aerospace) throughout the entire qualification
  - General compulsory core modules, followed by specific modules aimed at a specialisation in an industrial sector
  - General compulsory core modules, followed by a specialisation in specific AM processes
  - General compulsory core modules, followed by a specialisation in specific materials
  - General compulsory core modules, followed by a specialisation in quality and inspection

- In your opinion, which of the following weights of these methods in the metal AM MSc would best suit you, having in mind the meaning of following approaches to teaching and learning:-

  - Problem-based learning - method for students to have practical training, to collaboratively solve real problems, investigating and finding meaningful solutions, being the professor a facilitator and

  - Expository - traditional method of lecturing, led by the professor based in demonstration, memorising and doing assignments and homework. (Select only one answer).

    - 0% Problem-based learning - 100% Expository;
    - 25% Problem-based learning - 75% Expository
    - 50% Problem-based learning - 50% Expository
    - 75% Problem-based learning - 25% Expository
    - 100% Problem-based learning - 0% Expository

- Which of the following strategies should be used to deliver the MSc? (Select only one answer)
  - Presential learning
  - Distance learning
  - Blended learning (presential and distance learning lectures/tutorials)

- Do you expect to work closely to industry during the MSc?

- How important is it for you to work hands-on a machine during the MSc?
  - Not important
  - Important
  - Very Important

- According to the scale (1-3), please rate the following areas/contents regarding their relevance to the curriculum of an AM MSc:
  - AM processes
  - Numerical Modelling
  - Topology Optimisation
  - Design
  - Structural Integrity
  - Metallurgical Analysis and Characteristics
  - Post-Processing
  - Pre-Processing and material handling
  - Non-Destructive Testing
  - Certification and Validation
  - Testing / Quality Control
  - Standards
  - Costs
  - Health and Safety & Environment
  - Management / Business Administration
  - Other (please specify)

- Which type of supporting materials should be provided in the MSc? (Select all that apply)
  - Tutorials
  - Presentations
  - Handbooks
  - Videos
  - Database of materials (Handbooks, papers, tutorials, videos, presentations, etc.)

- Which of the following final evaluation tools, would you prefer to be evaluated with? (Select all that apply)
  - Oral exams;
  - Written exams;
  - Industrial project/report (individual)
  - Industrial project/report (group)
  - Thesis/research work (individual)
  - Thesis/research work (group)
  - Other (please specify)

- Which type of support and opportunities do you think should be provided in the MSc? (Select all that apply)
  - Wider support services and facilities (laboratories, IT system, library, administrative and social services)
  - Career counselling
  - Industrial experience
  - Abroad experience
  - Have an academic mentor
  - Have an industrial coordinator/supervisor
  - None
  - Other (please specify)

- What's your educational background? (Select only one answer).
  - Graduated in Mechanical Engineering
  - Graduated in Industrial Engineering

- Graduated in Welding Engineering
- Graduated in Materials Engineering
- Graduated in Design / Numerical Modelling
- Attending a bachelor's degree
- Attending a master's degree
- None
- Other (please specify)

Questions asked in Industry survey

- Type of organization:
  - Machine Supplier
  - Materials Supplier
  - Software Supplier
  - Services Supplier
  - End-User Automotive Sector
  - End-User Health Sector
  - End-User Aerospace Sector
  - End-User Energy Sector
  - End-User Metal construction Sector
  - End-User Maritime Sector
  - End-User Defence Sector
  - University
  - Research Organization
  - Other (please specify)

- Please select the required coverage/scope of the MAM Engineer qualification:
  - Cover all AM processes
  - Cover one specific process
  - Cover all materials
  - Cover one material

- Having as reference the following scale (Basic, Intermediate, Advanced), please rate the knowledge for the European MAM Engineer on the listed topics:
  - AM Processes
  - Subtractive Processes
  - Numerical Modelling
  - Topology Optimisation
  - Design
  - Structural Integrity
  - Metallurgical Analysis and Characteristics
  - Post-Processing
  - Pre-Processing and Material Handling
  - Non-Destructive Testing
  - Certification and Validation
  - Testing/Quality Control
  - Standards
  - Costs
  - Health, Safety & Environment
  - Other (please specify)

- Having as reference the following scale: 1 – 5, with 1 being 100% Theory and 5 being 100% Practical. Please choose the applicable weights of Theory and Practice for the European MAM Engineer on the listed topics:
    - AM Processes
    - Subtractive Processes
    - Numerical Modelling
    - Topology Optimisation
    - Design
    - Structural Integrity
    - Metallurgical Analysis and Characteristics
    - Post-Processing
    - Pre-Processing and Material Handling
    - Non-Destructive Testing
    - Certification and Validation
    - Testing/Quality Control
    - Standards
    - Costs
    - Health, Safety & Environment
    - Other (please specify)

- Please relate the Qualification with the required training topics. You can choose more than one item per Qualification:
    - AM Processes
    - Numerical Modelling
    - Topology Optimisation
    - Design
    - Structural Integrity
    - Metallurgical Analysis and Characteristics
    - Post-Processing
    - Pre-Processing and Material Handling
    - Non-Destructive Testing
    - Certification and Validation
    - Testing / Quality Control
    - Standards
    - Costs
    - HS&E
    - * Other (Please specify the qualification and/or the required training)

- Based on your organization requirements please identify the relevance/need of the different Professional Levels (1-very low and 5-very high):
    - Engineer
    - Other