UNIVERSITY OF CANTERBURY

DEPARTMENT OF MECHANICAL ENGINEERING

1st PROFESSIONAL YEAR

Mechanical Workshop Placement Written Report

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Core Builders Composites Limited

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Contents

1. Introduction

This report covers the Practical Mechanical Engineering work completed by a Mechanical Engineering Student at Core Builders Composites Limited in Warkworth over the 2014 – 2015 summer period.

It details the structure, products and ventures of the company in the global boat building, composite and engineering industry. Further, it describes the work undertaken by the Engineering student during the practical work internship, the problems encountered and the relevance of the work completed to the Bachelor of Mechanical Engineering degree.

2. Company Structure

2.1 Products and Services

The period of employment was completed at Core Builders Composites Limited, located at 73 Woodcocks Rd, Warkworth, approximately forty-five minutes north of Auckland City. The company is a derivative of the America's Cup Yacht Racing team, Oracle Team USA Racing. Primarily, it is focussed on the manufacture of America's Cup class racing yachts for the team. As a result of these projects, the company has acquired skills that put them at the forefront of carbon fibre composite construction technologies. The successes of the team in America's Cup competition have brought a positive reputation for quality to the company. Core Builders Composites passes on this knowledge in a consulting and manufacturing capacity for the construction of a variety of composite engineering projects around the world.

Figure 1 below is a photograph of the winning AC72 America's Cup Yacht, built entirely by Core Builders Composites in New Zealand and in the United States of America.

Figure 1: The winning Oracle Team USA America's Cup AC72 class yacht. [1]

2.2 Major technical processes

Core Builders Composites are market leaders in the development and manufacture of tooling solutions for advanced composite components. The factory in Warkworth has three dedicated CNC composite machines capable of machining to an accuracy of 0.2mm. This includes a CMS Poseidon high-speed 5-axis gantry CNC machining centre, which is one of the largest of its kind in Australasia. It is capable of direct-machining large-scale shapes and objects such as hulls, architectural supports or wind turbine blades. [2]

The company's specialist tooling knowledge has been developed for the marine industry through its contract to the Oracle America's Cup Team. However, this precision knowledge is relatable to many industries and has been further applied in public infrastructure, energy, architecture, and entertainment industry projects.

The advanced CNC machines permit cutting of high precision 2D and 3D forms, the production of precision moulds and plugs for composite applications, and an ability to machine complex CAD designs.

Additionally, bespoke composite manufacture and metal machining assignments are taken on when demand from the America's Cup team is low.

2.3 Facilities and Departments

Work was completed in several departments of the company. A large amount of time was spent on the factory floor of the composite manufacturing department and also assisting the engineers in the machine shop and CNC machining department. Additionally, a small amount of work was completed in the design department and the research and development department.

2.3.1 The machine shop

Core Builders Composites has a dedicated metal machining shop. It employs five skilled engineers, each of whom has their own specialisations. These include systems such as hydraulics, control units and precision machining of titanium parts. The machine shop incorporates two MAZAK CNC Machining centres and a MAZAK QT2000 CNC Lathe. These machines are capable of producing complex parts up to 2m x 0.6m x 0.6m out of any metal or industrial plastic, to a dimensional accuracy of 0.01mm. [2] The machine shop is a dedicated unit of skilled engineers who are responsible for fabricating all of the non-composite components on the racing boats. For example, they machine rope holders and high performance winches from lightweight metals. They also assist with the design and placement of control systems incorporating hydraulics and electronics incorporated within the wing trimming, steering and dagger-foil controllers.

Figure 2 below displays a CNC lathe used in the machine shop.

Figure 2: A MAZAK CNC Lathe in the machine shop at Core Builders Composites. [2]

2.3.2 The CNC machining department

Core Builders Composites has three dedicated composite CNC machines. All three can machine materials including foam, carbon, timber and non-ferrous metals, to an overall accuracy of 0.2mm. The smallest machine in the department is a MultiCam 3-axis CNC flatbed router. It machines parts on a 2.4m by 8.5m flat table. Typically it is used for 3D machining of foam core sets and 2D cutting of mould frames from plywood, MDF or pre-impregnated carbon fibre products. [2]

The second of the CNC machines in the department is the CMS Ares, which is a 5-axis CNC router with a working area of 6m x 2.6m x 1.2m. The Ares is often used to create smaller moulds and tools. For example, it was used extensively to machine moulds for the rudders, daggerboards and foam core sets for the boats sailed in the last America's Cup.

The largest machine in the CNC department is the CMS Poseidon. This is a 5-axis CNC high-speed gantry-machining centre with a working area of 18m x 6.2m x 3m. It can machine parts to an overall surface tolerance of 0.2mm. This machine is the largest of its type in New Zealand and one of the largest machines in Australasia. It was used extensively for large composite tooling for the ORACLE TEAM USA's AC72 yacht. It has also been used for industrial projects, such as a full-scale model of a MIG-29 aircraft, which was constructed from polystyrene.

The CNC machining department employs three full time engineers with the other engineers in the metal machining shop also assisting when necessary.

Figure 3 below displays the CMS Poseidon 5-axis CNC machine.

Figure 3: The CMS Industries Poseidon 5-axis CNC machining centre. [3]

2.3.3 The composites manufacturing department

The composites workshop is set up in accordance with aerospace industry best practice principles. This includes air-conditioned clean rooms, a negatively ventilated enclosed grinding bay and a dedicated gas-fired curing oven. The Wisconsin oven is used for the curing of composite components. It is capable of safely and efficiently running at up to 250°C and is monitored by thermocouples and vacuum gauges which log each cure cycle. [2]

It also incorporates the main workshop space, which is where the bulk of the construction of the racing yachts takes place. The department includes a large woodworking area and covers a combined area of more than 350 square metres. It employs thirty-five skilled boat builders, composite technicians and four apprentices. Typically it is the site where the construction of the largest elements of the boat is constructed, for example the hull. All of the components come together in this workspace to create the finished product, ready for shipping to the assembly site, which is in the country where the America's Cup competition takes place.

2.3.4 The design department

The design department consists of three skilled draughtsman and two professional mechanical and composite engineers. They are responsible for translating the engineering drawings that arrive from the design team in the United States into understandable workshop drawings. Their communication with the skilled boat builders, composite technicians and metal machinists is vital. They are responsible for ensuring production standards are met across all facets of the construction process. Additionally, they work with the senior management team to project manage and schedule the entire design, build and test phases of the project.

2.3.5 The research and development department

The research and development department is made up of the same draughtsmen and engineers of the design department, with the addition of a few skilled boat builders and the lead members of the New Zealand management team. Their role is to determine accurate methods of testing new components that have been built in the factory in Warkworth. The research and development team will then carry out the testing, both destructively and non-destructively, and record the data using stress and strain apparatus. The data is collaborated and sent back to the design and engineering team in the United States so that modifications can be incorporated into the design to improve the performance of the component. The design team is focussed on computational fluid dynamics analysis, static and dynamic loading analysis and materials selection for the components. Every effort is made to save weight and maximise strength in each component of the America's Cup racing yachts.

3. Staffing Issues and Management

3.1 Organisation and Management Structure

Core Builders Composites employs 50 full time employees at its Warkworth site. Tim Smyth is the manager and head boat builder. Under Tim, there are two highly experienced boat builders who act in the capacity of senior managers of the workshop staff. They are in charge of project managing and task scheduling the overall construction to insure the delivery requirements are upheld. There are two professional mechanical engineers on site as well as three skilled draughtsmen. Following this there are five skilled metal machinists, two trade certified engineers who look after the two CNC 5-axis machines, thirty-five skilled boat builders and composite technicians and five administration staff.

On top of these staff, there is also a broad skilled shore crew, most of whom are selected from the employee base in New Zealand. A base is set up in the United States or in the country where the America's Cup racing is taking place to assemble, maintain and test the boats. There are other professional engineers who are typically based in the United States and are employed directly by Oracle USA. They are the masterminds behind the design, material innovation, dynamic modelling, aerodynamics, in terms of the wing sail structures, and hydrodynamics, in terms of the foils that transform the yachts into low flying aircraft. Engineering drawings are received from the engineers in the US and are translated into workable production floor drawings by skilled draughtsmen in New Zealand.

The workforce is held together by a shared passion for innovation, the sport of sailing, materials technology and a will to win The America's Cup.

3.2 Personnel and Industrial Relations

I was fortunate enough to experience a wide variety of work environments during my time at Core Builders. Working on the workshop floor highlighted the camaraderie that exists between the skilled boat builders and also within the group of metal machinists. All of the staff were happy to engage in discussions over the tasks being completed. Each of them took pride in their work and was very willing to explain the intimate processes involved in construction.

A stable relationship was in place between the managers of the shop floor and the boat builders. The managers had worked their way up the ranks and had earned their respect through hard work and experience in their field. The ideas and opinions of every one of the employees were invited to be included in the eternal search for lightweight solutions to yacht construction. Some of the most notable innovations that helped Oracle defend The America's Cup were sourced directly from the shop floor and were developed all the way through to the management team and engineering group.

The very nature of America's Cup racing means that there are times when all of the members of the team come under serious stress. This necessitates effective management of all parts of the build of the boat. A positive relationship between the managers and workers was necessary to negotiate longer working hours in order to get the work done, as well as a positive team morale to ensure the production quality standards necessary for these extremely high performance yachts were achieved. The manufacturing quality of these racing yachts is of particular importance because the lowest factors of safety are applied in order to push the boundaries of performance and lightweight construction. This necessitates careful management of each stage of the build and a stringent assessment of production techniques in order to avoid catastrophic failure. The use of advanced carbon fibre composites places additional onus on the necessity of high quality construction, as they require careful handling and can be easily damaged if mistreated.

On the whole the workforce relate very well with each other. A positive dynamic exists in the factory and teams work hard together in the workshop and get on well together in the lunchroom. The company provides refreshments on Friday afternoons to show appreciation to its' valued team of construction workers. This is also a tactic by the senior management to maintain their relationship with the staff and to make the company an attractive and enjoyable place to work. Often work colleagues will work together on projects in their own spare time, which is indicative of their solid work ethic, passion for sailing and skill as craftsmen.

Tradesmen occasionally give apprentices a hard time. Typically the apprentices respond by picking up a broom and getting stuck in to earn the respect of their supervisors. For the most part there exists a very healthy working relationship between apprentices, tradesmen, draughtsmen and design engineers. The top tier management have a strong presence on the workshop floor and have all progressed through their own apprenticeships and trade qualifications.

3.3 Health and Safety

A dedicated health and safety and logistics manager was present at all times. A diverse range of tools and equipment and a large workforce dictated that the health and safety protocols needed to be carefully managed.

Upon arrival I was immediately given a full health and safety induction and shown emergency shut off switches and fire exits. A tool room was stocked with all of the necessary protective equipment for working with wood, metals and carbon composites. Carbon dust is extremely harmful if inhaled and can also become lodged under the skin causing severe irritations. The best possible equipment was provided by the company to ensure the protection of its' workers. This included face masks, full body protective suits, earplugs, safety glasses, gloves, covered shoes, overalls and filtered gas masks for painting, sanding operations and resin mixing. Toxic spill kits were easily accessible at all points of the factory. The factory was also equipped with fire extinguishers and a full fire alarm system. The most flammable and toxic of the resin and hardener chemicals and industrial cleaners were kept in isolated steel cupboards. As a new employee I was impressed by the seriousness with which safety was addressed. First aid kits and eye baths were also placed around the factory and any injuries were recorded immediately in the health and safety and ACC register.

At times when working in the woodworking section of the factory safety precautions seemed inadequate. This was overcome by returning to my supervisor for further training and assistance with use of the more hazardous machinery. Members of the workforce were all extremely competent with hand-held power tools and larger tools such as table saws and wall saws. They were always willing to pause their own work and instruct me on the best techniques of using the equipment to preserve my own health and safety. Forklifts and large gantries were often used and were only operated by qualified drivers with a high degree of care and attention to health and safety regulations. The factory was regularly cleaned and every effort was made to ensure that the work was conducted in a safe and comfortable environment. This ensured that the workers could work at their most efficient rate and to a high degree of quality.

Figure 6 below demonstrates the safety equipment that was provided for the workers protection.

(a) A 3M full face protective mask [4]

(b) A 3M protective suit [5]

Figure 4: Provided safety equipment.

4. Work Performed

4.1 Overview

I completed work in the composite manufacturing department, the metal and CNC machine shop, the design department and the research and development department. Primarily, I assisted with the build of the wing for the AC62 Class Yacht that will sail in the Bermuda America's Cup in 2017.

I was given a number of wood working assignments using workshop machinery. I was also involved in the process of making precision components out of carbon fibre. As a result, I was exposed to the importance of geometric dimensioning and tolerancing. Further, tooling and jig making was completed to assist the manufacturing process. Figure 6 below is a diagram of the table that I was responsible for building.

Figure 5: The table that I constructed as a base for machining foam moulds in the CMS Poseidon 5-axis CNC machine bay. [6]

I was also involved in the research and development team, assisting with the completion of destructive and non-destructive testing of carbon-composite elbow joints to be used in the dagger foils. I worked with skilled engineers in the metal chop to fabricate a reliable testing apparatus.

4.2 Cutting

My work placement at Core Builders Composites built on the practical skills that I learnt in ENME201 for the Warman assignment. This project required me to cut a variety of materials including aluminium and wood.

My first job was the construction of two 19 metre long tables that acted as a base for the machining of foam blocks in the CNC 5-axis machine. These were then used as moulds to construct the nose cone for the wing sail of the new AC62 out of carbon composites.

In constructing the table base, I used a number of cutting tools. I used a skill saw to cut flat panels of MDF. For the vertical carbon fibre panels that were used as bracing, I used a jig saw. Once this work was accepted and I had increased my ability and confidence level, I was able to use a router to accurately cut the table tops to within a tight dimensioning tolerance. I was also trained how to use a wall saw and a large table saw to cut large flat panels.

Work was completed with skilled technicians to carry out forming of wooden shapes for the moulds and plugs, and laying of carbon fibre over complex geometry shapes. For example, two weeks were spent manufacturing the nose cone of the upper section of the wing for the AC62. I used a circular saw to cut accurate lengths of timber and carbon fibre parts to help with the building process. For cutting small sections of carbon fibre, I used a band saw. This required careful adherence to the required speeds of the blade, so that the high strength carbon fibre could be safely and accurately cut.

These assignments assisted me to develop the accuracy of the skills that I learnt during the workshop-training course and during the build of the Warman robots in ENME201.

At all times when cutting careful adherence of health and safety regulations was required. Protective earplugs, safety glasses and a protective suit were worn at all times. Loose clothing was removed and the items that were being cut were held firmly in place using a mixture of guides, vices and clamps to avoid accidents caused by slipping.

Figure 4 below illustrates some of the machines that were used for cutting assignments over the summer work period.

(a) Example of a Band Saw [7]

(b) Example of Circular Saw [8]

Figure 5: Cutting Machinery.

4.3 Drilling

Building the large tables for the Poseidon CNC 5-axis to machine to required the use of a cordless power drill. A series of holes were drilled in the base of the table to bolt feet onto. These needed to be very accurately placed, as the placement of the feet in the machining bay was critical for the alignment of the part in the machine bay.

When assisting with the build of the nosecone and its mould, I used a drill press to accurately and quickly make holes in pieces of MDF to ensure the part was correctly aligned on its mould. This method also ensured alignment errors were avoided.

A special carbide drill tip needed to be used on the drill press when cutting carbon composite materials. Care was needed to ensure that heat build did not affect the structural integrity of the composite part or damage the drill tip. These skills were learnt in the workshop training course and were extended over the summer work period.

Safety precautions were carefully taken and were similar to those taken for cutting. This included wearing protective glasses, ear plugs and a protective suit. The part was secured using a mixture of vices and clamps, depending on its' size and shape. This was to avoid the drill grabbing and causing the part to spin uncontrollably. Figure 6 below depicts a drill press similar to one that was used at Core Builders Composites during the work placement.

Figure 6: Example of a drill press. [9]

4.4 CNC Machining and Metal Workshop

Over the time that I spent involved with destructive and non-destructive testing in the research and development department, I assisted the skilled engineers in the metal shop and the engineers who looked after the CNC machines.

I assisted the engineers to make a testing platform so that the material properties of an elbow joint, which is the structural component in the dagger boards, could be tested under tensile and compressive loads. This was achieved using a lathe to machine a large pin, which had to be thick enough to be attached to a large hydraulic ram. A mill was used to machine the shape of a large bracket and to drill a hole for the pin to slot in to. Problems with machining, such as the cutting tool getting close to the chuck, were avoided thanks to the advice of the skilled engineers and the ability to pre-program the coordinates to be cut into the CNC lathe. On top of this, the part was always secured well to the base of the mill using a vice, to avoid any slipping occurring. Coolant was employed to cool the piece that was being machined and to prevent any damage to the cutting due to heat build up. Health and safety routines were followed rigorously, with safety glasses, overalls and covered shoes being worn at all times.

Machine operating skills are necessary for projects throughout the Bachelor of Engineering (Honours) degree. Further, understanding of the processes that a skilled engineer goes through when fabricating components are useful to understand and will stand me in good stead over my professional engineering and design career.

A small amount of time was spent assisting the skilled engineer who was responsible for the CMS Ares 5-axis CNC machine. I assisted him with positioning parts correctly for machining in the machine bay and removing them after machining. It was very interesting to observe how he converted CAD drawings into CAM files and G-code that could be read directly as coordinates for the machine to mill. These skills were learnt in the key-tag assignment in ENME201, where we used CREO software to convert a CAD drawing into CAM files and code that could be read by a CNC machine.

Figure 7 is an image of the CMS Ares 5-axis CNC machining centre.

Figure 7: The CMS Ares 5-axis CNC machining centre. [10]

4.5 Drawing and Drafting

Drawing was necessary to help position the moulds that were mounted on my table bases accurately in the Poseidon bay. The moulds needed to be machined in the large 5-axis CNC machines to within an accuracy of 0.2mm. A small amount of CAD was completed to fulfil this role. This was completed with the assistance of one of the senior draughtsmen, who gave me an introduction to the Rhino CAD software package. I found the skills I learnt in ENME201 in Solid Works were very useful and I was able to quickly adapt to the new software.

Detailed engineering drawings also needed to be read and understood in order to facilitate this. Geometric dimensioning and tolerancing was applied in these drawings. This needed to be taken into careful consideration during the build phase.

4.6 Research and Development

I was involved in an investigation into the static loading capabilities of a major composite structural component in an America’s Cup Class Yacht. The elbow joint is a 90° curved radius composite design which forms the structural component of the dagger board foils on the Oracle Team USA AC72. The America’s Cup rulebook for the 2014 regatta stated that the design of the catamarans could include two adjustable dagger boards with two fixed rudders to achieve controlled low-level flight. These components are subject to static loads in the vicinity of 400 to 800 kilograms, considering the overall laden weight of the entire boat is in the region of 1.5 tonnes.

The aim of the experiment was to determine the maximum load that the dagger foil could withstand before failure. A number of loading conditions were modelled.

Figure 8 below provides an illustration of the experimental set up for the elbow joint tests.

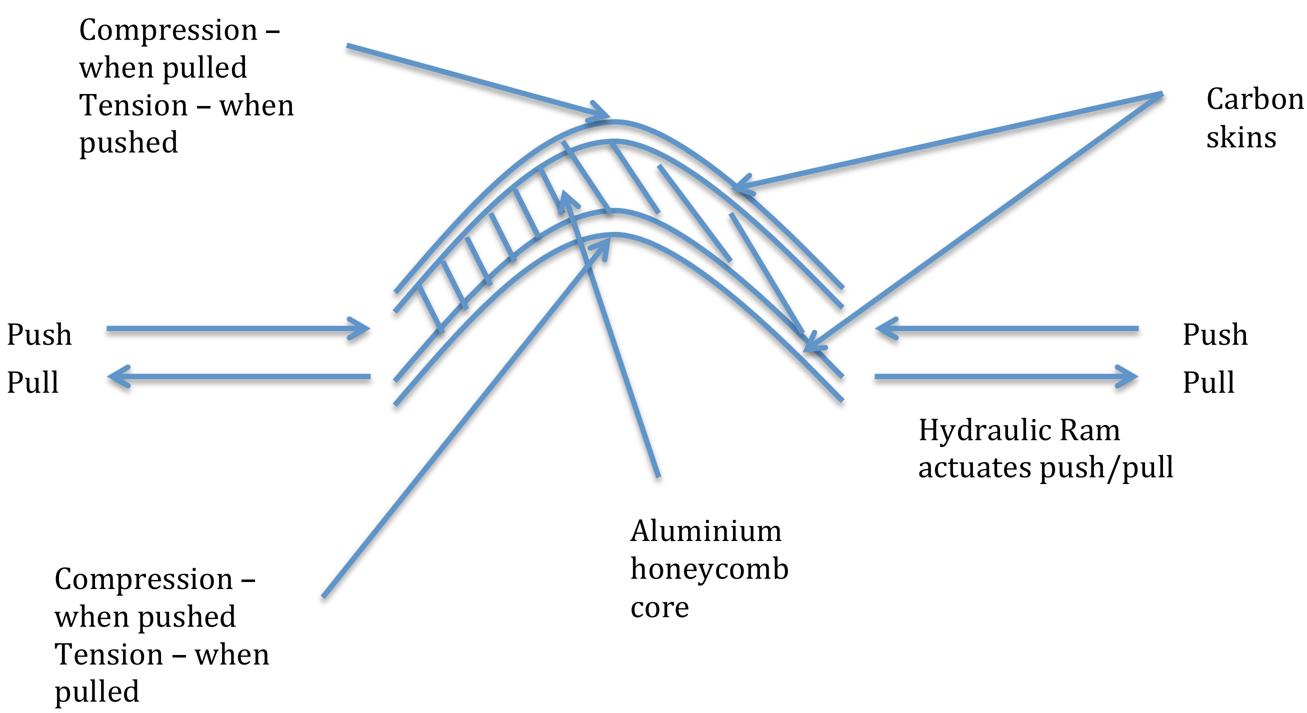

Figure 8: Experimental set up for the elbow joint tests.

Previously, the immense stress and strain that this area of the dagger board came under dictated that composite materials were unsuitable. This posed a significant challenge for the design and engineering teams as well as for the boat builders. New techniques were developed to modify an almost entirely composite construction to include other materials, such as metals, in areas that needed better fatigue loading capabilities or posed other demands that could not be met through composite carbon-fibre construction. Titanium was initially determined to be the best-suited material for this particular structural region. However, the inclusion of curved titanium strut into a carbon-composite body was difficult to achieve. Considering the fact that significant machine time and expense was dispensed in fabricating these titanium struts, a move was made to create a fully composite construction that could achieve the stringent demands and be as light as possible.

Historically, carbon composites have not been included in applications where significant fatigue loading occurs due to the risk of delamination and splintering of the carbon weave which drastically reduces strength. A carbon composite is made up of a rigid or flexible core encased in layers of carbon fibre cloth on either side. The cloth is impregnated with a blend of resin and hardener and laminated to the core. It is often heated in an oven to insure the resin and hardener mixture can set and bond with the carbon and core materials to achieve a structural connection. Depending on the intended applications of the part, a variety of core materials can be employed.

The test was run with the experimental set up displayed above in Figure 8. Stress and strain gauges recorded real time data. The professional composite and mechanical engineer, whom I assisted, recorded the data and sent it back to the design team in the United States to assist in the innovation of a lightweight structural solution for the dagger boards.

Safety was ensured by the placement of a Perspex screen between the test piece and the observers. Eye protection and ear protection was necessary as a loud crack was emitted from the test piece under destructive testing.

Non-destructive testing of the carbon-composite components could also be completed with tools such as infra-red heat guns and resonance. The consistency of the lamination of the carbon could be inspected by the method of resonance, whereby the piece was knocked and hollow points were listened for.

This type of test was very similar to those that have been recently completed for the ENME301 Perspex assignment. I was able to use my experience with destructive testing of materials to accurately determine elastic modulus and stress concentrations in my assignment as a result.

5. Conclusion

A variety of tasks and assignments were completed over my summer work internship at Core Builders Composites in Warkworth. These included a variety of woodworking jobs, including cutting and drilling, metal machining and assistance with large scale 5-axis CNC machining, lathing and milling. A mixture of hand tools and workshop machinery was employed to complete these tasks.

I gained an appreciation of how geometric dimensioning and tolerancing applies in the real world and learnt first-hand Mechanical workshop skills. Undoubtedly these skills will be useful over the remainder of my degree and in my career as a professional engineer.

I was fortunate enough to be exposed to some exciting mechanical testing for the next America's Cup yacht. I thoroughly enjoyed my work experience at Core Builders Composites and I am very grateful for the exposure to high level technology and advanced materials that it offered. This exposure will provide an inspiration in my future career and the skills that I learnt will be very useful.

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All websites were accessed on 30th and 31st March 2015.

I hereby certify that this report, except where indicated, is entirely my own work.

Signed:____

George Legget March 31st, 2014