

Manufacturing and Design with Engineering Polymers: Educational Aspects of a Specialist Dissertation in a Part-Time Elective Postgraduate Mechanical Engineering Degree Course for Industry-Based Students*

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The elective course on Manufacturing & Design with Engineering Polymers that is available to postgraduate students on the Master of Engineering Design degree programme at National University of Ireland, Dublin, uses active learning to teach students about processing and performance-related issues pertinent to polymer engineering for Irish industry. A significant element of this course is undertaken by students preparing a specialist dissertation that is pertinent to their particular industry and employer and which simultaneously implements and illustrates many specific topics on the course syllabus (e.g., viscoelasticity, deformation and fracture, processing, design for manufacture, design for strength, etc.). The case of a recent student, employed as a full-time R&D engineer by a company manufacturing viscoelastic pressure relieving pads, is used to illustrate the practical educational issues that arise when implementing such a teaching method. The method of education by means of a specialist dissertation, proved to be an effective and popular teaching method in that specific concepts that were integral to the aims and objectives of the Manufacturing & Design with Engineering Polymers course were learned actively by the student. This method of teaching works well with relatively small class sizes but does require a tutorial style of involvement between course teacher and students. It is recommended that uses of this method of teaching within the present context of the Master of Engineering Design degree programme be explored further.

INTRODUCTION

THERE IS a broad range of seventeen optional courses available to students of the Master of Engineering Design degree programme. This is a taught Masters degree programme which contains some component of project work; the nature of the project work would typically be of direct relevance to the industrial employer of the particular student and, as such, the project would be considered to be either applied research or development and would seldom be fundamental in nature. The emphasis of these seventeen courses on the degree programme is heavily biased towards mechanical engineering and they cover the spectrum of teaching and general research interests of the members of academic staff within the Department of Mechanical Engineering at the National University of Ireland, Dublin. Students are required

to read for eight of these elective courses in addition to undertaking Design Project Work over a period of two years. All lectures are scheduled for Fridays and Saturdays during the academic session, with students completing course work and assignments in between their ongoing work commitments. This model of one day release per week from employment has generally proven to be satisfactory for employers, students and course lecturing staff alike.

Candidates embarking on this Master of Engineering Design programme are required to have attained an honours standard in an engineering or scientific discipline coupled with some relevant industrial experience. All students generally are employed full-time within industry whilst undertaking the course; students usually find that their career progression accelerates after completing the course. Because it is not a prerequisite for incoming students to already hold a primary degree in mechanical engineering, or to have

* Accepted 15 January 1999.

obtained equivalent knowledge through their professional experience, all the courses that are taught on the Master of Engineering Design programme must, as a minimum result, ensure that all students have the opportunity to attain equivalent levels of understanding and knowledge at the end of the course. Essentially this means that a differing amount of each course will cover material that would have already been taught in an undergraduate mechanical engineering degree programme.

From the seventeen courses listed that are available on the Master of Engineering Design degree programme, and the design project work, students who are employed within a particular sector of industry can identify a combination of subjects that provide useful specialist knowledge for their particular requirements and circumstances.

- Design Methodology & Practice
- Computer Aided Design
- Design of Machine Elements
- Materials Selection
- Production Systems, Design & Management
- Design of Automated Manufacturing Systems
- Microprocessor Applications
- Digital Electronics Design & Interfacing
- Tribology & Design Applications
- Technology & Innovation Strategy
- Design of Internal Combustion Engines
- Design of Thermal Power Plant
- Micro-climate Management Design
- Design of Building Energy Systems
- Polymer Matrix Composite Materials: Performance & Design
- Manufacturing & Design with Engineering Polymers
- Design of Biomechanical Systems

The syllabus for the single semester course on Manufacturing & Design with Engineering Polymers, which is taught by the author, covers many processing, performance and design topics that also would be taught on a course on engineering polymers during an undergraduate degree programme in mechanical engineering. However, the depth to which these topics are taught is more concentrated, advanced and specialised when compared against the undergraduate course work. Additionally, some element of choice is available to students from course topics such as:

- extrusion
- injection moulding
- blow moulding
- thermoforming processes
- rotational moulding
- dies and moulds
- environmental issues
- viscoelasticity
- yield and fracture
- design for manufacture
- design for stiffness
- design for strength
- design for maintenance and disassembly.

The element of choice is provided to students by virtue of the fact that the final grades for this particular course are awarded for a specialist dissertation and an end-of-year examination. The focus of the specialist dissertation is required to be based on the experience of the individual candidate and should illustrate the implementation of many of the particular topics on the syllabus of the course, thereby providing an active learning experience for the particular student.

This article provides a synopsis of the specialist dissertation that was prepared by a recent student of this particular course on Manufacturing & Design with Engineering Polymers. The student is an R&D Engineer employed by Company X, which manufactures and distributes a range of pressure relieving pads suitable for head, neck or torso use in the operating theatre to prevent the onset of pressure ulcers both during operation and post-operatively during recuperation. The main constituents of these products are a silicone gel which is encapsulated in a polyurethane film.

As part of the ongoing development of new product ranges and potential new markets, Company X concluded that the possible use of alternative materials to the relatively expensive silicone should be explored. From this background, and within the context of the scope of the Manufacturing & Design with Engineering Polymers course of the Masters of Engineering Design degree programme, it was appropriate that the specialist dissertation be in the form of a survey of existing and potential alternative pressure-relieving devices, followed by a preliminary investigation into the likely performance of the potential device that was considered to be most suitable for development into a new product.

The work undertaken towards the specialist dissertation involved investigating a number of options such as polyurethane gels and polyvinyl plasticisers. However, the concept that was chosen for further development was an oil elastomer combined with an oil liquid. Experimental work focused on the determination of optimum processing parameters and subsequently on testing the product under simulated wear conditions. Results were found to be of sufficient quality to justify further pilot process development work and the specialist dissertation concluded with the recommendation that further processing trials be carried out on a larger scale.

The present paper focuses principally on the manner in which the objectives and syllabus of the Manufacturing & Design with Engineering Polymers course are integrally learnt through this particular specialist dissertation. These are actively learnt by a student while resolving a particular problem, namely, identifying a feasible solution to the development of a new range of pressure relieving pads. This involved researching a market segment and scientific literature to identify possible polymeric material systems that could be used in the design and manufacture of a specific

product. A single solution was selected from the range of material alternatives, appropriate processing parameters were determined, and a range of prototype laboratory test specimens were manufactured and tested to ascertain the mechanical performance of this chosen solution. The paper concludes with some comments on the success of this particular teaching method.

BACKGROUND TO THE PROBLEM

While pressure sores occur mainly among elderly patients [1–4], there is also a high incidence among spinal injury patients and long-term wheelchair users of all ages [5]. It has also been established that some operations are of such significant length as to be the cause of pressure sores due to the dead weight of an anaesthetised patient. This situation is exacerbated by the trend towards longer and more complicated operations. Industry sources estimate the amount of money spent annually by the National Health Service (NHS) in Britain on the treatment of pressure sores at between quarter and half a billion pounds. This, coupled with the ever increasing potential for litigation and the resulting large damage awards, would suggest that if efforts were instead concentrated on the prevention as opposed to the treatment of pressure sores, both of these costs could be dramatically reduced.

Such statistics have motivated research into the design and construction of various types of mattresses [6] in an effort to prevent tissue damage due to localised pressure concentrations on a small area of skin. Over the past two decades a large variety of support surfaces for the treatment of pressure sores has become commercially available. These supports vary considerably in their design, cost, reliability and ease of use. The majority reduce local pressure concentrations by redistributing body weight over a large area, for example, foam mattresses, flotation beds and static air pads. The clinical effectiveness of a mattress is often cited in terms of the interface pressure between the body and the support surface. High peak pressure areas surrounded by areas of low pressure are to be avoided as this leads to a steep gradient between applied pressure over adjacent areas of soft tissue, and consequently gives rise to shearing forces. Pressure sores caused by shearing forces often involve deep structures and may develop ischaemic necrosis of the tissues. This can ultimately require surgery if the bone becomes diseased.

For the prevention of sores it is necessary to understand four factors which affect interfacial pressure between the body and the support surface, namely: unrelieved pressure, shear and friction, moisture build-up, and poor nutrition.

A modern pressure ulcer prevention and management system begins by assessing the potential that a patient has to develop ulcers. Although

there is no one single preventive measure for avoiding pressure ulcers, it is generally wise to give priority to the relief of pressure since this is the greatest contributory cause of pressure ulcers. Two ways of relieving pressure and restoring the skin's blood supply are to reposition the patient and to use special devices. This can be done by developing a turning schedule so that the patient is moved every two hours—from side to back or from stomach to side [7]. It is helpful to make minor changes such as altering the angle of an arm or leg even more frequently. Specially designed pads, mattresses, pillows and other accessories are also widely used.

It is important also to keep the skin clean and lubricated but free from excess moisture. This can be done using talc-free powders or barrier creams and appropriate incontinent devices if necessary. The breakdown of skin can be prevented by reducing friction and shear forces. Patients are less likely to slide down in bed if they are supported by pillows and if the bed is not angled too steeply. Assistive devices can be used to move patients in and out of bed when ever possible. Good nutrition can be promoted by giving the patient foods that are high in protein and calories as well as vitamin supplements. Cells will regenerate more quickly under these circumstances.

From the preceding discussion it is clear that the greatest single cause of pressure ulcers is high interface pressure values at bony prominences. An average pressure of 32 mmHg at a point just beneath the skin is currently accepted as the threshold of externally applied pressure above which small vessels collapse and thrombose, resulting in occluded blood flow and consequently in the deprivation of oxygen, nutrients and lymph circulation. This can lead to ulcers and ultimately to skin breakdown. The range of pressure relieving pads currently manufactured by Company X attempts to combat the conditions which cause pressure ulcers by increasing the area of contact between the body of the patient and the pad. In theory, if the area of contact is increased then any bony prominences are less prominent and thus the interface pressure is spread over a wider area and the pressure gradient is less steep. An ideal pressure relieving pad should have the ability to allow a body part 'sink' into the pad in a controlled manner without the pad 'bottoming out' so that maximum cushioning is achieved. It also should reduce the instances or possibility of friction or shear occurring between a patient's skin and the pad by virtue of being sufficiently flexible to move with the body.

AVAILABLE PRODUCTS AND CONCEPTS

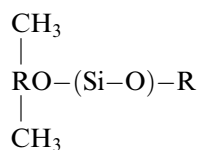
The main constituents of the current range of products manufactured by Company X are silicone gel and polyurethane film. Silicone is a totally

inert non-reactive material which is highly suitable for this pressure relief application. However, silicone has received much adverse publicity in recent years due to its use in breast implants and the suggestion that it can cause health problems. Silicone gel is an expensive commodity costing approximately £7 per kilo; this contributes almost 90% of the total product material cost. The original products manufactured by Company X tended to be small products such as headrings, armpads, etc. However, as the range developed customer requests called for larger products such as full length operating theatre table pads and, thus, cost became an increasingly important issue. Consequently, a major challenge is to reduce the cost of the product to the user by replacing the silicone gel with an equally good, if not superior material.

Silicone elastomers

Cured silicone elastomers are chemically inert and, consequently, are suitable for biomedical applications. The physical properties are not affected by temperature. Thermal stability is very important when the material is in contact with the body as the temperature of the body and its environment is continually changing. Silicone also shows resistance to weathering which is important for the long-term life of the products. Young's modulus decreases from 10 GPa to 200 MPa between -50°C to 25°C and remains constant up to 260°C . This means that the stiffness of the elastomer is constant up to a very high temperature. Thermal conductivity of silicone rubber increases with increasing filler content so that a pressure relieving pad can reach body temperature quickly. Cross-linking and fillers reduce permeability; gels are weakly cross-linked systems and even contain substantial quantities of free fluids. This makes it possible to achieve a loose structure which replicates human flesh.

Silicone elastomers are formed when silicone polymers are cross-linked with appropriate molecular weights; this gives the elastomeric properties. Phenyl, vinyl and hydrogen can substitute for the methyl group in the silicone chain. The substitution, branching and molecular weight of a silicone polymer will dictate the method by which curing can be accomplished. The filler affects thermal and electrical properties and may be a finely divided material such as silica. These materials are outstanding in low temperature flexibility, stability at high temperature and resistance to weathering. The structure of a silicone elastomer is:



where R represents hydrogen or an organic radical. There are two types of silicone elastomers

available, namely room temperature vulcanised rubbers (RTVs) and heat cured rubbers although it is RTVs which are used by Company X.

RTV rubbers are uncured rubbers with a liquid or paste-like consistency based on intermediate molecular weights and viscosities. Curing is based on chemical reactions that increase molecular weight and provide cross-linking. Catalysts provide the cure control.

RTV silicones may be subdivided into one- or two-component silicones. One-component RTVs have the composition of polymers, fillers, additives, curing agents and catalysts. The time required for cure depends on the curing system temperature, humidity and the thickness of silicone layer. The filler, original polymer properties and cross-link density affect the ultimate strength. Modulus, tensile strength, tear strength and abrasion resistance all increase with particulate silica. The reinforcing effect depends on particle size, structure and surface interaction. Commercial products based on polydimethylsiloxane substitutes other than methyl modify and improve certain properties; e.g. trifluoropropyl groups improve solvent resistance. These rubbers offer a broad spectrum of product properties.

Two-component RTV silicones, on the other hand, are less prone to self-bonding than one-component materials. Primers are applied where adhesion is necessary. The cure reactions of one-component products are triggered by exposure to atmospheric moisture. Those of two-component products are triggered by mixing the two components, one of which consists of or contains the catalyst; the two components are supplied separately.

Alternative solutions

Patent index, scientific and trade journal searches indicated that systems other than silicones merit consideration as pressure relieving materials; these other systems included polyurethanes, PVC plasticiser compositions, oil extended elastomers and various water-based systems including thixotropic suspensions [8–12].

The high mechanical compliance demanded by the ultimate pressure pad is only likely to be met by a gel system. A gel consists of a molecular network swollen by a liquid medium. The liquid prevents the gel from collapsing into a compact mass and allows network mobility in response to applied stress. The liquid must interact with the network through secondary bonds. Conventional hydrogels based on gelatine and water are typically held together by relatively weak hydrogen bonds while in the silicone gel currently used by Company X, primary chemical bonds play a greater role.

The mechanical properties of gels depend primarily on the properties of the polymer network. As the pressure pad requires very low hardness and a high degree of viscoelasticity, a high level of molecular mobility is predicted. Silicones have a very low glass transition temperature, typically

-20°C, as a result of the relatively free rotation about the Si-O-Si bonds and it is this factor which gives the present system its useful properties. Following deformation, the gel returns to its original shape because of the tendency of any loosely associated molecular assembly to adopt the most random formation, i.e., elasticity. However, the recovery of the network is viscously retarded. Human flesh has a similar response and thus the silicone system has the appropriate constitutive properties for use in pressure relieving cushions.

Any alternative material would need to have a chain backbone with a similar flexibility and capacity to bind with large amounts of liquid. In general, those systems which are known to give low hardness compounds and which have reasonably easily managed processing routes are plasticised vinyl compositions, polyurethanes, thixotropic systems and hydrogels, and oil-extended elastomers.

- **Plasticised vinyl compositions.** These are compounds of a base vinyl polymer, with the addition of plasticisers to give softness and necessary processing stabilisers. The base polymer provides the network and the plasticiser acts as a swelling liquid. Plasticisation can lower the glass transition temperature of PVC from 82°C in the pure polymer to around 40°C. Stabilisers are also required to allow the polymer withstand the elevated temperatures needed to facilitate entry of the plasticiser into the polymer. The base polymer used could be either polyvinyl chloride (PVC) or vinylchloride-vinylacetate copolymer (VC-VAc). The requisite softness could only be obtained by using what is, by normal PVC compounding standards, a very high plasticiser content. In order to ensure high absorption of plasticiser, an emulsion polymerised material with a very high surface area would be required and a high efficiency primary plasticiser such as diallyl phthalate (DAP) or dioctyl phthalate (DCP). Patents by Weber and Burke [11, 12] describe the use of such highly plasticised PVC compounds in shock absorbing systems and in wheelchair cushions. Formulations and constructions are specified. It should be noted that there is increasing concern about the use of chlorinated plastics for health and safety reasons. Raw material costs however would be low. A possible technical difficulty would be the difficulty of heating a relatively thick section as some of the current pressure relieving pads manufactured by Company X are up to 100 mm thick.
- **Polyurethane.** Polyurethanes are the products of reaction between a diisocyanate and a polyol. The urethane link is relatively flexible and if the crosslink density is low and interlink moieties are inherently flexible then very soft materials can be produced. Two isocyanates dominate the field, namely TDI and MDI. Toluene diisocyanate (TDI) is principally used for manufacturing flexible foams. It is highly reactive and presents significant handling and safety problems. Methylene di-p-phenylene isocyanate (MDI) is used in rigid foams and elastomer systems. It has a lower reactivity and a much lower vapour pressure than TDI and thus handling and safety problems are significantly reduced. The polymers can be produced by mixing together a low molecular weight hydroxy-terminated low polymer (the polyol) and an isocyanate. By varying the nature of these components, a wide range of properties can be achieved. PU gel systems are already in use for shock absorbing and cushioning applications. These materials, while cheaper than silicones, would still be relatively expensive when compared with other options.
- **Thixotropic systems and hydrogels.** The thixotropic systems are based on magnesium silicate in one of its many forms. This material has the ability to 'bind-up' large amounts of water and forms an extensive temporary secondary bonding system. The resulting suspensions behave as solids at low stress levels but when subjected to high normal or shear stress or high rates of strain they fracture or flow depending on the precise composition. On removal of the shear flow, they revert to their former condition. This technology is widely used in the paint and plastic industry to control the flow behaviour of fluid systems. Various types of purification and chemical modification may be carried out to improve their compatibility with the fluid and to increase their swelling response. Bowker and Davidson [13] discuss the use of such systems to provide cushions that will deform at pressures below those necessary to cause capillary closure (30–40 mmHg). The benefit of such a system is that if the curing temperature is below this value then the cushion will continually adjust its shape to minimise local pressure peaks. These systems would be available at a much lower cost than silicone. However, it was felt that the properties of Bowker and Davidson's material [13] would be more suitable to a wheelchair cushion application than a pressure relieving pad since they would be likely to 'bottom-out', thereby exposing the patient to the potentially hard surface beneath the pressure pad.
- **Oil elastomer.** Oil extended block copolymer systems appear in a number of patents. Chen [8, 9] basically refers to the use of such compositions for medical support cushioning. The systems referred to are based on thermoplastic elastomers, typically ethylene, butylene and styrene and are extended using a plasticising oil. Elastomers such as the Kraton G series referred to by Chen in his patents are relatively hard and it is the function of the plasticising oil to soften them. A block copolymer containing polystyrene end blocks is used as part of the chain and is incompatible with the polyolefin component. The styrene phase separates out and

acts as temporary crosslinks, eliminating the need to use chemical crosslinking to obtain mechanical stability and full elastic recovery from deformation. Oil extension is a standard procedure in the rubber industry and is used to soften, to modify hysteresis and to cheapen compounds. What is different in Chen's patents [8, 9] is the use of a thermoplastic block copolymer and very high levels of plasticising oil. Typical rubber-to-oil ratios in hard rubber compounds might be around 100:40. The advantages of oil elastomers are the very low cost, wide ranging mechanical properties, novelty value due to the relative newness, and the inertness and safety of the material.

Concept chosen

It was not possible for Company X to pursue all of the options identified in the patent search and consequently one concept had to be identified. Design innovation is a priority for Company X and the cost and novelty advantages offered by oil elastomers, coupled with the possible technical limitations of curing thick sections of plasticised vinyls, the relative expense of polyurethanes and the limitations of using thixotropic systems, meant that oil elastomers were selected as the first choice material system.

EXPERIMENTAL WORK AND RESULTS

Processing parameters

Having sourced possible oil elastomers and compatible oil liquids, it was first necessary to determine appropriate processing parameters in order that potential oil elastomer pressure relieving pads could be manufactured for trial testing. This involved determining the most suitable grade of oil elastomer and oil liquids, a percentage mixture of oil elastomer and oil liquid, mixing times, vacuuming times and curing times. This required the preparation of a series of mixtures of varying combinations of oil elastomer and oil liquid which involved heating the elastomer to above its glass transition temperature, T_g , until it dissolved, thoroughly mingling the elastomer and the oil, placing the mixed liquid into suitable polyurethane bags and finally curing the mixture at an appropriate temperature for a suitable length of time. All air bubbles that may have been introduced during the different stages of the whole process were removed by using a vacuum tank. Having optimised the processing parameters, a small number of prototype products were produced in the different grades of oil elastomer for in-house testing purposes. It is worth noting that the elastomers that were initially selected were triblock oil elastomers and were all of similar composition without any significant difference.

Performance parameters

It was necessary to perform a number of preliminary investigations to ascertain the constitutive

Table 1. Interface pressure test (mmHg)

Silicone	O.E. GRP6917	O.E. 1651E
11.02	11.17	12.02
10.87	11.57	12.82
11.62	10.15	13.80
13.02	11.05	11.25
11.08	9.07	11.60
10.82	10.22	12.25
11.45	10.82	11.84
13.10	13.04	12.15

relationships of the oil-based elastomer and to compare these against the range of properties associated with the current silicone-based pressure pads. The range of tests that were carried out to establish the mechanical performance and viscoelastic response of the oil-based elastomers are described in general terms below.

- **Interface pressure.** The interface pressure is the pressure between the patient's skin and the surface of the pressure pad. As mentioned previously, medical research indicates that capillary pressure is 32 mmHg and the aim of any pressure relief product should be to keep the pressure as far below this value as possible. Pressures greater than 32 mmHg can cause the capillaries in the body to collapse, thereby causing a lack of oxygen, nutrients and lymphatic circulation. Twenty-four products in all were tested: eight existing silicone pads and sixteen oil elastomer pads: eight O.E. GRP6917 and eight O.E. 1651E compounds. All were 10 mm thick and were tested on a Talley interface pressure monitor under identical circumstances (Table 1). All pressure readings are in mmHg.
- **Deflection.** This is the distance in mm which a 10 kg mass will sink into the current silicone pad over a period of 30 minutes. From historical data a deflection of less than 50% of the product thickness is acceptable as this implies that a certain level of cushioning is being achieved without the product 'bottoming out', i.e., without the top and bottom surfaces of the pad cover from coming into contact with each other by laterally displacing the pad support material. Twenty-four products in all were tested: eight silicone pads, eight O.E. GRP6917 and eight O.E. 1651E products. All were 10 mm thick and

Table 2. Deflection tests (mm)

Silicone	O.E. GRP6917	O.E. 1651E
3.2	1.4	1.4
3.75	2.9	1.6
3.4	1.2	1.8
2.4	1.1	1.6
3.4	1.1	2.5
3.6	0.8	1.6
2.9	2.5	1.8
3.2	2.7	2.1

deflection was measured after 30 minutes under identical conditions (Table 2).

- **Dynamic roll test.** The product is subjected to a continuous folding and rolling action which is repeated frequently for a relatively long period (every 20 seconds over 22 days). The product moves from a flat position to one where it is folded in half. It is then rolled open into a flat position again. For this test a product was put in a chamber and continuously folded and rolled mechanically to simulate hard wearing. Both oil elastomer products under test performed similarly after 22 days. There was no permanent damage to the product but it was slightly creased although the creases disappeared over a five day period.
- **Weight test.** The product under test is folded and placed under a 25 kg weight to assess its ability to withstand the weight of a sizeable body part such as a leg and to regain its original shape. For this test the product was folded and placed under a 25 kg weight for 11 days. Both oil elastomer products performed similarly. There was no permanent damage. Slight creasing disappeared over three days.
- **Peel test.** This test measures the adhesion of the gel to the polyurethane film. A sample piece approximately 4 inches long by 1 inch wide was cut from a larger product and the film peeled from the gel. The tests were carried out on a Lloyd DVM3 tensile tester (Table 3).

Table 3. Peel tests

Product	Force required to peel PU film from gel (N)
Silicone	32.00
O.E. 1651E	1.35
O.E. 0RP6917	0.80

DISCUSSION

Technical results

Both grades of oil elastomer show huge potential as replacements for silicone in the current range of pressure pads manufactured by Company X. While a lot of progress has been made in establishing the optimum parameters in manufacturing oil elastomers it is expected that further changes could be made to improve the properties of the final formulation.

The interface pressure values are on a par with the current silicone-based system. However, the lower deflection results described in Table 2 indicate a less responsive gel which will not give as much cushioning to the body. This is of some concern and improvements would have to be made to the viscoelastic stiffness before an oil elastomer could be used. This could possibly be achieved by reducing the percentage of oil within the compound. The dynamic roll test and the weight test results were encouraging and based on these

preliminary observations it can be concluded that the oil elastomers would perform as expected by the market.

However, the peel tests detailed in Table 3 indicate an almost total lack of adhesion between the oil elastomer and the polyurethane which would be a very serious concern in the market place. Delamination of the film from the gel in the marketplace would be considered an unacceptable failure. Work should focus on sourcing an alternative film which would have better adhesion to the elastomer. Previous difficulties with delamination from silicone were solved by corona treatment of the PU film. While this will not work with the oil elastomer, it does indicate that it may be possible to find a solution.

There are reasons why Company X would wish to continue with the development of the oil elastomer. It is a relatively new material which does not appear to have been commercially exploited to any great extent. It would be a brave move for Company X to move from a silicone product which is doing well in the market to an oil elastomer but it could well be an innovative one which would influence market trends. An oil elastomer costs approximately 25% of the cost of a silicone elastomer and this would permit the development of larger products which would be affordable to the market.

Due to health concerns over silicone in the last ten years, a move away from silicone would be seen as a positive step in some markets. Indeed, one of Company X's competitors promotes the fact that their product uses a polyurethane gel rather than a silicone gel. Silicone is in fact a far safer material, particularly from a processing point of view. The manufacturers of the oil elastomer compounds have been approached with a view to taking the development work to the next stage. Company X are committed to scaling up the process to a pilot scale provided that the lack of adhesion difficulty can be improved. Work plans and project time scales are currently being prepared.

Educational issues

Unlike industrially related projects on many other degree programmes, it is customary that there is no industrial supervisor for the project work (i.e., specialist dissertation) of particular courses, such as the course currently under discussion, namely Manufacturing & Design with Engineering Polymers. The reason for this is that such project work forms a relatively small part of the overall degree and the purpose of this course project is to actively educate the student about certain topics that are specific to the course in question. Separate project work towards the degree would most likely draw on material associated with more than one course and would commonly involve some form of industrial supervision. The practical significance of this lack of industrial supervision of the project work which forms the basis of a student's specialist dissertation

is that the details and scope of the project work must be defined quite precisely at the beginning of the course by both the student and the academic course director to ensure that the necessary range of topics (e.g., viscoelasticity, deformation and fracture, processing, design for manufacture, etc.) will be addressed in the project and that the scope of the project is neither overly ambitious nor insufficiently substantial to be completed within a single semester. This can be achieved by the student providing a two-page project description within one week of the first student/lecturer contact meeting. This project brief should be redefined within a further one week if the scope or content of the project is not completely appropriate. In addition to the ongoing contact between student and lecturer, it has been found helpful if an open-door policy is adopted whereby additional meetings can be arranged when either person considers that such a meeting is necessary to expedite progress of the project. It is certainly useful to both the student and the lecturer if a draft of the specialist dissertation is provided two or three weeks prior to the final submission deadline; this does not permit additional research work to be undertaken but it does enable a student to make minor amendments to aspects of the dissertation.

There are quite fundamental differences between the project work of such a course and an industrial placement where a project is undertaken in industry. An industrial placement project would essentially only occur on a full-time degree programme and the project work would most likely be defined largely by an industrial supervisor. The course project work described in this paper is essentially undertaken by a student who is working full-time in industry and who is studying for the Master of Engineering Design degree on a part-time basis. The purpose of this type of project work is essentially intended to educate the student about fundamental principles of the course. No emphasis is placed on the industrial practice since it is expected that the student, who is already employed within industry, is familiar with such issues.

It is somewhat difficult to determine the benefits that accrue to the industrial company from the specialist dissertation as compared to those which would be associated with alternative means of obtaining the particular project results. Alternative, and more immediately focused research methods could include undertaking in-house R&D, external subcontracting, or recruitment of specialist expertise. Many project activities that would be suitable for a specialist dissertation would ideally be undertaken as a matter of good business strategy (i.e., a company should develop, own and possess its own R&D capabilities to maintain its long-term competitive advantages). It is the opinion of this author that the single biggest advantage that a company acquires by having an employee undertake such a specialist

dissertation is that the student/employee has the opportunity to learn the formal and fundamental details of a particular subject such as manufacturing and design with engineering polymers. This serves the dual purpose of adding to the knowledge basis of the company and the employee (who may not have studied such subjects at undergraduate degree level and who may have only acquired a basic knowledge through their day-to-day work) in a manner which is time efficient.

The performance of a student on this particular course is assessed both by considering the specialist dissertation and by an end-of-year examination. The project work and the report are examined to determine the level to which the student appeared to have understood the particular fundamental concepts. In this instance, the understanding of polymer physics, chemical structures, viscoelasticity, deformation of polymers, and design and manufacturing with polymers were all assessed.

CONCLUSIONS

The specialist dissertation that was carried out towards the requirements of the elective course on Manufacturing & Design with Engineering Polymers successfully identified a possible substitute material, based on oil elastomers, for current generation, silicone-based pressure relieving pads. Preliminary research into the processing and mechanical performance of these oil elastomers suggests that it should be possible to manufacture innovative pads using these materials which are significantly less expensive than conventional silicone pads without sacrificing mechanical performance. Current work is focusing on the development of a more in-depth series of processing and performance trials to optimise the behaviour of oil elastomeric pressure relieving pads.

This method of education by means of a specialist dissertation proved to be an effective teaching method in that specific concepts that were integral to the aims and objectives of the Manufacturing & Design with Engineering Polymers course were learned actively by the student. This method of teaching works well with relatively small class sizes but it does require a tutorial style of involvement between course teacher and students. It is recommended that further uses of this method of teaching within the present context of the Master of Engineering Design degree programme be explored.

The current structure of the Master of Engineering Design programme is almost exclusively focused towards mechanical engineers. It is suggested that a broadened series of elective courses from other engineering disciplines could prove to be even more popular with potential students from a wider section of industry.

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