Creative Recycling of Waste Glass as a Tool for Teaching and Learning

FINAL REPORT on CETLD project

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Introduction

This project was funded by the Centre for Excellence in Teaching and Learning Through Design, CETLD, at the University of Brighton. CETLD aims to enhance learning and teaching in design through research, with a particular stress on contributions to pedagogy. The project was lead by the School of Environment and Technology and involved collaboration with the School of Architecture and Design and the participation of CETLD partners from the Royal College of Art and the Victoria and Albert Museum for artistic aspects. Dr M Philip of London Metropolitan University participation on the project resulted in valuable consultations on materials science for waste recovery and recycling and product design. He is the author of a number of publications on the subject [1-3].

The inspiration for this project was in response to the CETLD Learning Challenge: "To deepen our understanding of research-led learning within a resource-rich environment. This involves examining further the effectiveness of teaching methods, peer learning and the evolution of better constructive alignment of learner intentions, outcomes and assessment criteria "

The objective of this project was to contribute to students creativity and learning by providing facilities and wide expertise for

(1) developing designs and prototypes using waste glass, also in combination with other materials; and

(2) learning about material properties using glass in a practical laboratory environment.

Firstly, with decrease in global resources and increase in environmental awareness, embedding sustainability and eco-issues into undergraduate teaching is seen as a priority. The goal is to encourage cross-pollination of ideas on creative recycling, for the students of various routes, including art and design and engineering.

Secondly, the project aims to address the growing concern of tutors for the students who lack the mathematical and technical skills to confront the study of technical subjects. This is seen as a problem on a national scale and hence the search for learning approaches that work for this cohort.

The project enabled setting up a new facility for creative glass recycling. It is equipped with glass granulator, range of furnaces and glass cutter.

This project aligns with an earlier CETLD project on 'Exploring the relationship between teaching and learning through practice' by Alma Boyes, Cynthia Cousens, Helen Stuart and the students MDes Materials Practice (www.brighton.ac.uk/design/cetld). There is a shared intention: 'The overarching aim to explore the relationship between teaching and learning through practice, in order to develop innovative modes of delivery to enhance teaching'. They have researched how tutors teach and students learn through demonstration including observation, emulation and how they use this as part of the creative process. The project looks at more effective methods of teaching, the role of new techniques to support teaching by demonstration and it evaluates the role of live performance.

In comparison to this earlier CETLD project, our project looks at how practical learning through demonstration and hands-on experience can be delivered to different types of students at different stages of their learning cycle with different goals and different backgrounds. There were several types of students catered through the project.
The students were:

(1) undergraduate students of SET in their first year of study, including various routes such as Mechanical Engineering, Aeronautical Engineering, Electrical Engineering, Product Design, Sports Technology and Design Technology,

(2) undergraduate students of Faculty of Arts and Architecture,

(3) postgraduate students from SET (MSc Product Innovation and Development students, MSc Civil Engineering students and a PhD student).

Methodology

For the undergraduate students, data was qualitative with assessment. The research environment was a laboratory classroom. Laboratory sessions for more than a hundred of undergraduate students have been devised and implemented into existing modules, DP134 and XE121 of School of Environment and Technology. The sessions were two hours long. The students were at the first year of their studies and the objective of the lab sessions was to teach them scientific concepts (such as phase change, heat capacity, thermal stresses) and material properties (brittleness and ductility; opaque and transparent materials and their degree of crystallinity). Glass processing methods (slumping, fusing, melting and casting) were directly shown to the students in the lab whilst giving many of them a chance to work with glass hands-on. Practical observations of glass properties and behaviour at high temperatures constitute the basis of critical reflections on fundamental concepts such as the dependence of viscosity on temperature, amorphous and crystalline solids and the transition temperatures.

The sessions were tutor led with active participation of the students. The data contributing to this project was by observation and classroom response as assessed by the tutor and by feedback questionnaire from the students.

For the postgraduate students, individual one-to-one sessions introduced the students to the lab and its equipment. The students were mostly MSc PID students who had 6 months full-time to complete a project. In this category, Mr I Lizarralde, Miss Lia Afentouli have earned high marks for the MSc PID project and successfully graduated in the duration of the project. Miss J Salazar, Miss N Moshidou are continuing their work for 2009. A PhD research by Mr V Bugas of SET is under way. These are the students directly supervised by EM and ES with consultations from the partners on the project and the Design Mentor.

The project also catered for the students supervised by other lecturers. A series of consultation surgeries for Mr J Diaper of School of Arts and Architecture have been provided in spring 2008 by recommendation of Dr J Kermik. Consultations on waste

glass granulation to Miss Thomi Argyroudi, MSc student supervisee by Dr F Gunzel of SET, were given in spring 2007.
Apart from several introductory sessions for postgraduate students, the rest of the time was a student-led independent research time to allow them to create new ideas and products using recycled glass. Brain-storming sessions and regular consultancy surgeries on the students ideas were held by by EM and ES. They constituted an integral part of the students'research whilst feeding into observations made by the tutors for the project.
They will be described in more details in what follows.

Undegraduate teaching at School of Environment and Technology

As an outcome of the project a laboratory workshop on creative glass recycling for more than a hundred of undergraduate students have been devised and implemented into existing modules, DP134 and XE121 of School of Environment and Technology, see Appendix 1. Each student had a two hours long glass workshop session on creative glass recycling. It was run in conjunction with the theoretical material covered in the lectures for the modules .

Several glass properties were explored in the laboratory, such as glass viscosity, glass transition temperature, thermal expansion, thermal stresses, glass toughening and annealing. The students were each given a lab handout on the day or ahead of the lab sessions. There were live demonstrations and study of pre-prepared samples during each session. A series of tasks were set in the course of a teaching session.

The task: explain the significance of glass viscosity. Glass viscosity changes with temperature. The lab handout presented a graph of viscosity versus temperature and a table indicating viscosities and what glass processing techniques may be performed at the specific viscosities of the glass. As an introduction to viscosity, the students were shown products with their normal viscosities at room temperature, as in oil versus honey etc. It was not received well, the students simply nodded. When asked to look at the graph and relate it to the viscosities in front of them, again the level of engagement was minimal. There was no indication that they could relate this to a continuous change in material viscosity with temperature.
Result: unsatisfactory

The task: a tutor demonstration of the viscosity change with temperature. The tutor had prepared a glass melt in a furnace before the start of session. The oven temperature was very high (1300°C) and so it was necessary to perform the experiment quickly. The idea was to show the students that glass has a low viscosity at high temperature and thus can be drawn to thin fibres. Also, that when the glass is above the glass transition temperature, it is not brittle any more, and so patterns (*e.g.* spirals) can be made while drawing the fibre.

With time (in a matter of minutes) as the air cooled the furnace and the melt cooled, the drawn fibre became increasingly thicker as the viscosity increased. Furthermore the cooled glass fibre was now below the glass transition temperature and was now brittle and subject to thermal stresses.

Result: the students enjoyed the demonstration especially when seeing the red hot furnace but when asked to explain the outcome of the experiment, there were few volunteers. It was not clear to the tutor that the students appreciated the science behind the experiment. Perhaps there were too many principles being explained all at the same time.

The task: examination of a pre-prepared sample of glass for application of principles.

The tutor had brought a toughened glass sample that had been prepared in advance to demonstrate the thermal properties of glass. A detailed study of underlying principles and phenomena were covered in the lectures but it was felt that the students find it rather academic and complex.   When on the lab day, the demonstration has been performed, the students' eyes brightened with understanding and motivation. It was a refreshing change from their glazed eyes at the lecture.The bulk glass sample demonstrated the thermal stresses that can develop during the cooling of a cast glass and the significance of annealing. It should be observed however that when asked to explain deeper why the bulk glass sample appeared as it did, the students had difficulty making the connection. Hence the next task.

The task: to demonstrate thermal cracking. A few glass bottles was placed in the furnace by the students at the start of the session. An hour later, the students took turns removing the bottles from the furnace and quenching it in water. Thermal cracking of a waste bottle creates an attractive pattern – a weblike criss-cross of fine cracks. The purpose was to demonstrate the thermal properties of materials. The students were directly involved in the experiment. There were 15 students to a group at a time and in pairs all of them had a go.

Waste glass bottles before and after thermal cracking experiment

Result: At the end of the session, all of them understood the concepts of thermal expansion, thermal residual stresses and glass annealing. The class became animated and excited. There was a great willingness to participate.
They were so delighted with what they had done. The students ask to take the bottles home to use as gifts and candlesticks.

The task: to demonstrate slumping, this is again to bring home the point that glass can be worked at different temperatures. Again a bottle was placed in a furnace at the start of the session, at a higher temperature than for the thermal cracking (~ 850°C) C. An hour later, the glass had collapsed and flattened down. A student was asked to volunteer to take tongs and press the glass to make an indentation and also to attempt to fold the corners. Several more wanted to try but there were not enough furnaces and there were some disappointed faces.

Result: The earlier experiments were all reviewed and students were asked to describe in their own words the experiments and the outcomes, including the earlier fibre drawing exercise. Now more than 50% of the class had an opinion and they were mostly right. They asked to explain again the earlier toughened glass sample pre-prepared by the tutor and there was now an appreciation of the process.

The task: impact of an experiment. In the next class session, the order of the experiment was reversed. The slumping was performed first and the thermal cracking later. The enthusiasm and impact of the slumping experiment was less than in the earlier sessions when it followed the thermal cracking.
Result: The thermal cracking experiment received the best reaction.

As a conclusion, it appears that combining an engineering concept with an aesthetic feature to facilitate the teaching process is an effective teaching methodology.

From these lab sessions, a questionnaire was distributed among Year 1 Design students of School of Environment and Technology in March 2008. It read:
‘Did you learn more about glass, its properties & processing, and recycling issues through the laboratory session than without it? Explain your answer.’

A reply by Miss Sarah Burleigh, DP134 student of SET, reads:
‘The waste glass lab was very beneficial to me as I learned more about glass, its properties & processing, and recycling issues. I feel it is better to show things practically as it actually shows you what the lecture was teaching us about. And if the information I received in the lab was taught during a lecture I don’t think I would have understood the whole issue. As I am more of a practical learner I feel if this was purely taught in lectures I wouldn’t take or learn much at all. I feel that if the labs didn’t exist, a lot of students would be completely lost or getting the wrong end of the stick as it could be described.’

Overall students' feedback was quite positive. A quantitative version of questionnaire was distributed among the students of DP134 and XE121 modules of School of Environment and Technology. This aims to gauge the success of the project for the undergraduate teaching. The results are shown in Appendix 1.

Postgraduate teaching and research

The project had made a substantial impact towards postgraduate research. The presence of the new facility for creative glass recycling has attracted students. Several research projects on innovative solutions for waste glass applications have been accomplished under MSc Product Innovation and Development (PID) degree study.

Each MSc PID student started with a literature review of the current state of waste management and the value of recycling. As part of the introduction to their project topic, there is an analysis of the amount of waste glass available and how much is destined to landfills. There is an assessment of the benefits of recycling in terms of saving raw materials, reduction of waste and implications for carbon counting.

The input to practical learning started in the laboratory. After health and safety considerations, the following tasks were carried out.
The task: how to operate an equipment. All the students came without previous knowledge.
The methodology: the tutor demonstrated the operational procedure by going through the steps with them on a one-to-one basis. No previous hand-outs.

The equipment: glass granulator. The operational sequence involved: turning the power on, feeding the glass into the granulator, turning the power off and collecting the granulated glass from the output.
The result: the students easily understood and carried out the procedure.

The equipment: an analogue furnace. The operational sequence involved: turning the power on, setting the temperature, ramping it up, handling the glass before and after and power off.
The result: the students easily understood and carried out the procedure.

The equipment: programmable furnace. The operational sequence involved programming the sequences of temperature, ramp and dwell using the built-in programme. The tutor repeated the demonstration twice per session while the student took notes. A diagram of how temperature, ramp and dwell were related accompanied the tutor demonstration.
The result: they could not operate from reading from their own notes even when left alone to try it. A third session, without the student looking at her notes in which the tutor reiterated the sequences during the demonstration, has finally worked.

The tutors' observation on the variation of the theme:

(1) The students who took notes during the demonstration did not pick up as well as the students who simply observed and paid attention to the demonstration and made the notes later at their own time when left alone with the equipment.
(2) The students who read the operational manual before the demonstration, did not benefit from it. They still needed the three sessions. This was observed irrespective of the technical background of the students.

Tutors' reflection:
(1) The benefit of prescriptive demonstration of a complex procedure is to focus the student on the task, asking them to concentrate and allowing them the time to understand the language of the machine. The experiential part of learning must follow immediately after the prescriptive demonstration.
(2) For the students who were not as focussed because they were taking down notes during the demonstration, the third session when the student had a chance of operating the equipment on his own helped him follow the procedures more easily. This agrees with the observation of the project "Exploring the relationship between teaching and learning through practice" (www.brighton.ac.uk/design/cetld): '*Machine Shop* was a lecture style demonstration of approximately 2 hours, where the machines and equipment were explained but not used. In questionnaires, when asked if they felt they could use the techniques demonstrated: several students commented that they needed to try the processes in order to learn them, or use the machines in order to be confident with them. Experiential learning was important to the students.'

The MSc students needed to create products using recycled glass for their projects. It is important that a student learns how to work the glass. The sessions with the student was individual tutoring following the methodology:

The student is first shown by the tutor that glass viscosity changes with temperature and can be soft enough to pull into fibres. This is a tutor only demonstration and similar to the demonstration mentioned above for the undergraduates.

The second demonstration was the slumping example. Here both the student and tutor worked together in producing a product, the tutor and student went through how glass softens at different temperatures, how the appearance changes and how to work it at these temperatures.

The third demonstration was the thermal cracked glass bottle prepared by the undergraduates. The MSc student understood the concept easily even without experiential learning. As this stage of their education, they already had a grasp of technical principles.

The tutors' observation:
There is good communication in teaching individually this way. The student confidence in handling glass is readily apparent. In the presence of a tutor, the student is confident in handling glass for the first time.

In these laboratory sessions, the student learnt about the required temperatures in the furnace to process glass for various tasks (slumping, fusing, melting, casting).The student learnt to assess how much time they had to execute a process – the temporal and thermal stages of glass handling. While they had no fear in handling the hot material, they were surprised at how quickly the physical properties of the glass changed.

From only two sessions, the students could work independently in the laboratory and exercise their creativity.

The student output during the CETLD period was impressive. The following students benefited from the CETLD project:

A patent application on TinGlass construction brick with Mr M Bataineh, MSc PID student, is in the progress. The brick is produced by fusing or melting waste glass cullet in a waste steel can. The brick has good mechanical properties comparable with natural stone.

TinGlass™ Construction brick: a concept

TinGlass™ Construction unit: manufactured prototypes

A recent work by Miss Lia Afentouli, MSc PID student was focused on practical and decorative types of waste glass objects. She has arranged large pieces of glass partially covered by soil in a waste wooden box as an alpine flower bed rockery. The glass rockery has been produced by melting and fusing waste glass that was granulated on-site.

A method of manufacturing decorative waste glass tiles was designed and implemented in the course of her thesis work using on-site facilities. The tiles are mechanically strong and they can be used for paving, internal or external wall finish and lampshades.
The MSc PID course Leader, Dr Steve Plummer, gave a highly positive feedback on the CETLD contribution to the MSc PID projects, see Appendix 2

A rockery and a tile made of waste glass,
Miss Lia Afentouli, MSc Product Innovation and Development,

Low cost and scalability of the prototypes mentioned above for commercial implementation is the subject of an on ongoing MSc PID research by Miss N Moshidou.

Mr Ibon Lizarralde, MSc PID student of SET has got an award with merit in October 2008 for the project that combines waste glass and plastics waste. He has critically assessed and adapted a known process for dissolution of polystyrene (PS) foam in acetone. The resulting gooey paste has many applications including bonding glass cullets and preparing tiles for embedding into mortar for wall finish.

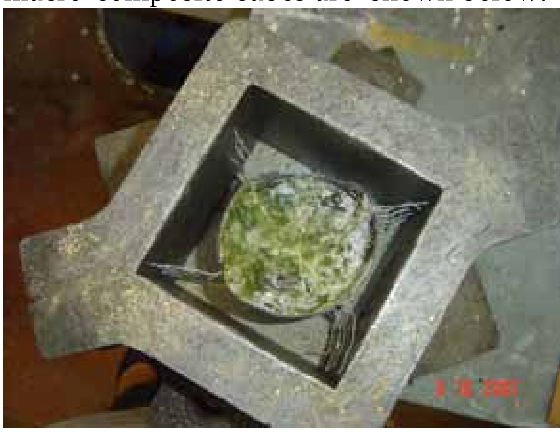
Tiles made from polystyrene foam, acetone and glass cullet by Mr I Lizarralde, MSc PID.

Mr Lizarralde and other postgraduate students attended the exhibition Material and its Form organised by Dr J Kermik and Miss N Pipe of School of Architecture and Design, May 2008. In his MSc PID Thesis, Mr Lizarralde describes the the exhibition and reflects on the inspiration and vision it gave him, as shown in Appendix 4.

Miss J Salazar continues her project on waste glass products. Some of her works are shown below.

Waste glass bricks by Miss J Salazar, MSc PID

A PhD student, Mr V Bugas, presented a paper at the international conference ***SB08MED*** on sustainable construction in January 2008. This paper assesses eco-characteristics of waste glass prototypes such as CO2 footprint and embodied energy. Savings of non-renewable materials when replaced by recycled glass are estimated. Further continuation of this work is planned by Mr Bugas under his PhD research programme. He is performing mechanical testing to construction industry standards, to characterise the properties of macro-composite material composed of TinGlass units embedded in concrete. The process of placing TinGlass unit into the mould and the resulting concrete macro-composite cubes are shown below:



The compression testing of TinGlass block embedded into concrete has been performed in accordance with BS1881. The testing has shown 20% higher compression strength of the composite (Tinglass block embedded into concrete) than that for a standard concrete block. Results of macro-composite beams in bending obtained through current research of Mr V Bugas, are quite promising. They are not fully disclosed here because of the confidentiality issues.

<u>Contribution to teaching process at School of Architecture and Design, Faculty of Arts and Architecture</u>

Interdisciplinary research continues to be explored through collaboration with CETLD Design Mentor, Dr Juri Kermik of Faculty of Arts and Architecture. A visit of group of staff and students of Faculty of Arts and Architecture to the glass processing facility in February 2008 has paved the way to the cross-disciplinary collaboration between students and staff.

The students were given a presentation on waste glass processing and sustainable practices. The students have familiarised themselves with the available equipment and its capabilities for their design work.

One of the students, Mr J Diaper, has arranged a series of individual work sessions at the workshop for his project. He produced his design pieces for the exhibition *Material and its Form* in May 2008.

The exhibition was attended by MSc PID students of SET, Mr I Lizarralde and Miss J Salazar, and by Mr V Bugas, a PhD student at SET. The comments made by the students have shown that the SET students were very impressed by the artistic angle of view and bold design solutions of the Arts and Architecture students.

Museum resources for teaching

The students were encouraged to use museum resources such as Victoria and Albert museum. The benefits were made clear to them during lectures and individual meetings and surgeries in the glass workshop.

- Miss Lucille Mcparland, Final Year Design student, has visited Glass Gallery at V&A in April 2008 for enhancing a historical and cultural perspective when working on her design project in waste glass.

- Mr D Allistone, Year 1 Product Design student, has attended the Glass Gallery at V&A in 2008 for his design work.

- A 2007 Design graduate, Mr Alex House has contributed towards iGuides CETLD project by giving his impressions of the Glass Gallery.

- Two MSc PID students, Miss J Salazar and Mr I Lizarralde, have visited Glass Gallery at V&A in May 2008 for the work on their projects on waste glass

Links to local industry

Links to local industry producing table tops made of waste glass were followed as the tool for enhancing teaching process. This was developed following the CETLD guidance on the novel TTURA resin for bonding glass cullet into a beautiful and durable material.

Social and educational aspects of the projects

A recent Innovation Award by Business Services of University of Brighton in June 2007 has demonstrated an organic growth into social and economical dimensions. The idea of a Glass Workshop Studio Social Enterprise open to the general public was recognised by the award as contributing into education of the general public in sustainability. It can give an outlet to creativity in glass for underemployed people whilst alleviating the problems of waste glass landfilling. A collaboration between University and local public through Social Enterprise will contribute to social cohesion.

Dissemination of the project

A seminar on the project has been given by Dr Manzanares and Dr Sazhina in February 2008. It was followed by the CETLD exhibition of waste glass products developed by the students

The exhibition *Material and its Form* based on desigh from waste glass, was organised by the Design Mentor for the project, Dr Juri Kermik and Miss Nikki Pipe. It has helped to establish links between student communities of SET and School of Art and Architecture.

A presentation by postgraduate students of SET on their work in waste glass was made at eco-festival *Greenwave* at Preston Park, Brighton, July 2008. This was in collaboration with local company Magpie Coop.

The results of the project have been presented at Sustainable Forum, University of Brighton, July 2007 and July 2008, and at a conference on Education for Sustainable Development (ESD), University of Brighton, October 2008

External events included exchange of visits with University of East London in summer 2007 for a consultations on products from waste materials.

Collaboration with a local company Float Design Glass, is under development through the work on the project. An exploratory visit to a local company Float Design has been made by ES and EM and postgraduate students in September 2008. The company works on slumping glass; their products have high aesthetic appeal. A preliminary suggestion has been made by the company manager of donating some samples of the glass to the University, and acquainting students with their work. This will allow linking the technical dimension with the aesthetic enjoyment of slumped glass fro the students. company http://www.floatglassdesign.co.uk/ seen 15/10/08

Established links with EightInch Ltd will be cultivated further after the project. The company produces RESILICA, a product for table tops from waste glass, of high aesthetic and technical quality. Familiarization with RESILICA samples will encourage the discussion of technical aspects relevant to the module syllabus, whilst combined with observation of the aesthetic features of the product. http://www.eightinch.co.uk/ seen 15/10/08

Conclusion

The thermal cracking experiment had the best response in the glass laboratory session in terms of understanding the concept and willingness of the students to participate in the learning process. The observations from our classroom experience indicate that combining teaching of technical concept with an aesthetic feature facilitates the learning process. The challenge for us as teachers is to create similar experiments, conveying difficult technical concepts in simple experiments where the end product is a thing of beauty.

We have made the following observations in relation to demonstrations:

1. As much as possible, everyone must have a go. Two students per experiment seem to work.
2. It must be short. After the preparation by the teachers, the students hands-on must be ~10 minutes each.
3. If possible, there should be some samples or objects they can take away with them.
4. We note here that something like ‘this is one I (the teacher) made earlier’ had a muted response unless the visual product is beautiful as in the thermal cracked bottle.

Beyond undergraduate teaching, the concept of aesthetic appeal extends to the postgraduate students. Their ability to be creative and be productive is in proportion to the beauty of the product. Thus, Miss Afentouli worked on her own initiative, with muct creativity and determination, to produce beautiful glass objects whilst more mundane work (concrete casting for embedding them into a product) was prone to delays and lack of interest.

Miss Johanna Salazar who produced beautiful glass brick to start with, followed it up readily, without any suggestion or push from the tutors, to create another 10 or so using her own initiative. She varied shapes, colours and was highly inventive in designing steel moulds for her tiles. The inspiration was visibly in front of her, in what she is capable of making and how beautiful they all were.

Finally, the results show that the project organically grows in many directions. It is seen as a creative way of addressing sustainability issues in teaching and learning process. It helps to build bridges between artistic and technical camps at the University, and possibly between local public and University staff. The creative growth of the underlying idea motivates and inspires students for their academic study and broader awareness of environmental and social issues.

References:

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"Producing wealth from waste glass: ecological, commercial and social dimension", In *SB08MED*: (Jan 2008)
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as seen 8/11/08

Appendix 1

Review of the questionnaires distributed in spring 2008 among the students of DP134 and XE121 modules of School of Environment and Technology

The assessment of the impact of the project through questionnaires has been launched in accordance with guidelines of CETLD.

A workshop on the ethical approach to using images and setting questionnaires for the students, has been attended by Dr E Sazhina in spring 2008.

The students were given a clear description of the aims of the CETLD project.
They were given seven days to reflect on the participation in the questionnaire.

The results are shown in Table 1 for the XE121 module (a mixed group of Level 1 mechanical engineering and Level 1 electrical and electronic engineering students).

Table 2 shows the results for the DP134 module (Design students of Product Design, Sports Technology and Design Technology pathways).

Please tick against your choice:	Number of entries by the XE121 students	Comments
It was very helpful	6	
It was helpful	8	
It was unhelpful	1	This entry was made by an Electrical Engineering student who felt that the subject is not relevant to his study
It was very unhelpful	0	

Table1. Results of the questionnaire for assessing the impact of the two-hour laboratory session on waste glass recycling by the students of XE121 module, SET

Please tick against your choice:	Number of entries by the DP134 students	Comments
It was very helpful	7	
It was helpful	4	
It was unhelpful	0	
It was very unhelpful	0	

Table2. Results of the questionnaire for assessing the impact of the two-hour laboratory session on waste glass recycling by the students of XE121 module, SET

The text of the questionnaire and accompanying cover sheet is shown below.

XE121 **17 April 2008**
Assessment of Laboratory sessions

Dear XE121 students,

Please read the questionnaire below and you are invited to submit your answers next week 24/4/08 9.00 W512.

The participation in the questionnaire is voluntary.
This questionnaire will have no influence on the assessment process of the XE121 module. You do not need to submit your name on the questionnaire unless you wish to do so.

The results of the questionnaire will be used for the assessment of the XE121 module by the School of Environment and Technology management and External examiners.

They will be also used for the assessment of the CETLD project on ***Creative Waste Glass recycling***, http://cetld.brighton.ac.uk/projects/current-projects/creative-recycling-of-waste-glass as seen 12/4/08

You are well acquainted with the XE121 module through attending the lectures and lab sessions, January – March 2008, also by reading through the lab scripts on StudentCentral and working on your lab reports.

Creative recycling of waste glass for sustainable design

Did you learn more about glass, its properties & processing, and recycling issues through the laboratory session than without it?

Please tick against your choice:	
It was very helpful	
It was helpful	
It was unhelpful	
It was very unhelpful	

Comments:

DP134 **Technology 1** **12 February 2008**

Student's name (optional)

Assessment of Laboratory sessions

Dear DP134 students,
Please answer the questionnaire below by ticking a box:

Creative recycling of waste glass for sustainable design

Did you learn more about glass, its properties & processing, and recycling issues through the laboratory session than without it?

Please tick against your choice:	
It was very helpful	
It was helpful	
It was unhelpful	
It was very unhelpful	

Explain your answer if you wish.

Appendix 2

20 January 2008

Dr Elena Sazhina

Dear Elena

Miss Evangelia Afentouli

University of Brighton student number 03825294

I have known Lia for over four years, whilst she studied in the School of Engineering, and latterly in the School of Environment & Technology, at the University of Brighton. In the first year of her undergraduate course, I was her Personal Tutor and one of her main lecturers. In the final year of her undergraduate course in 2005/2006, I was her Project Supervisor for her major project entitled, *The design and manufacture of a minimoto carburettor suitable for module ME105*. Lia was awarded a third class honours degree in Mechanical Engineering.

Since then, I have been her Personal Tutor and one of her main lecturers on the postgraduate course in Product Innovation & Development. Lia joined the course on the Postgraduate Certificate pathway and progressed to the Postgraduate Diploma pathway, and then to the MSc pathway.

I was delighted to hear that in the space of 15 months, Lia has improved her performance from a third class honours degree standard, and at the next Examination Board is to be considered for an overall credit classification, helped by gaining a mark of 63% for her MSc Project. Significant value has been added to Lia's education by her undertaking a MSc Project entitled, *Innovative technical solutions for waste glass processing*.

Thank you for supervising Lia's MSc Project in such a positive way and bringing Lia's time with us to a successful conclusion.

Yours sincerely

Steve

Dr Steve Plummer, BSc Hons (Aston), MSc (Cranfield), PhD (UMIST)

Principal Lecturer in Manufacture & PID MSc Course Leader

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Appendix 3

School of Environment and Technology **DP134 Technology 1**

Creative recycling of waste glass for sustainable design

Aim: Learning through practice about glass recycling, glass properties, design and fabrication of useful and decorative products made of waste glass

Objectives:
By the end of this activity, the students

1. will learn about optical, thermal and mechanical properties of glass and glass ceramics
2. will familiarize with sustainability issues and waste glass collection challenges
3. will learn glass processing techniques with emphasis on energy efficiency
4. will be encouraged to see waste glass as a creative media

Sustainable Design in Glass
Recycling is a way of preventing useful material resources from being wasted; it also reduces the consumption of raw material, energy usage and greenhouse gas emissions. Sourcing materials from domestic and industrial waste for decorative and useful products, and finding new opportunities and innovative solutions to environmental problems should become a key motivation for a designer.

Traditionally, glass melting starts from dry chemicals or powders and melting is at a high temperature for a long time to support chemical reaction and homogeneity. In starting with pub glass (waste beer and wine bottles), both glass melting temperature and time are reduced, thus conserving material and energy. Every tonne of waste glass used for producing new glass items saves about 315kg of carbon dioxide [5].

The UK imports more household glass (such as wine and beer bottles and the like) than it exports so there is a surplus of waste glass. The total annual waste glass produced in the UK is estimated at 3.6 million tonnes (Mt). The UK glass industry has the capacity to recycle over 1 Mt of glass each year. The remaining 2.5 Mt of glass was landfilled in 2001, www.glass-recycling.co.uk as seen 12/12/07. Landfilling of waste glass creates an environmental problem by occupying land practically indefinitely due to low degradation of glass with time.

Waste glass such as beer and wine bottles (pub glass) constitutes a more pressing ecological problem in the UK than clear glass because most wine industries are located at far destinations (USA, France, Australia) and reusing the bottles is not an option.

Creative recycling of waste glass

Glass is increasingly used in our buildings and homes, and future designers should learn how to incorporate it in their designs.

Glass is a sustainable material. It can be endlessly remelted without any deterioration in its properties, and it is sourced from waste glass products such as beer and wine bottles thus addressing sustainability and recycling issues.

In this study, you are encouraged to think of the ways of using recycled glass as a creative media after studying its properties and ways of processing, under action-based and inquiry-based learning approach.

This study will use museum resources, in particular Glass Gallery of the Victoria & Albert (V&A) museum and Royal College of Art (RCA) in London.

Glass processing facilities

A waste glass recycling workshop has been opened in 2006 at School of Environment and Technology, University of Brighton. It is equipped with a glass granulator and a range of high-temperature furnaces (operating up to 1300°C).

The project is sponsored by funding from CETLC InQbate http://www.inqbate.co.uk/ and WERG **(**www.brighton.ac.uk/werg). It has also attracted funding from CETLD, http://cetld.brighton.ac.uk.

Links to local industry:

Waste glass is available through a collaboration with Social Enterprise **Magpie Cooperative**, www.magpie.coop. A collaboration with a local table-tops producer EightInch www.eightinch.co.uk is being established.

Learning approach: problem-solving and practice-oriented case study

The learning process will be set as a case study of domestic waste glass recycling aiming at giving it a problem-solving character. Practical work will be combined with the academic study of materials science concepts and glass properties**.**

Glass Properties

[1] pp .435-437

1. Thermal processing of glass is defined by its **Viscosity**
2. Mechanical properties: **Brittleness**
3. Optical properties: **transparency and colour**

It what follows these concepts will be revised in detail

Viscosity

The main parameter governing glass processing and fabrication process is **viscosity.** Viscosity (η) is a measure of the *resistance* of a liquid to *shear deformation*.

SI units: $\eta = (N \cdot m)/(m^2 \cdot (m/s)) = (N/m^2) \cdot s$ = ***Pascal-sec***

Note: 1 Pa-s = 10 P Poise is the traditional unit used by glass scientist.

Table 1 shows the viscosity ***η*** measured in (Pa-s) of some materials at room temperature. The viscosity-temperature characteristics of the glass are important in the glass-forming operations. Figure 13.6 of [1] plots the logarithm of viscosity versus temperature of some familiar glasses.

There are a number of important reference points that describe the viscosity-temperature characteristics of a glass melt.

1. Melting Point: (n ~10 Pa-s); melt is fluid enough to be considered a liquid.

2**.** Working Point: ($\eta = 10^3$ Pa-s); temperature at which the molten glass can be deformed or manipulated; at this point the viscosity is low enough for glass processing by pressing or blowing, but high enough to retain some shape after the force is removed.

3. Softening Point: ($\eta = 4 \cdot 10^6$ Pa-s);.

4. Annealing Point: ($\eta = 10^{12}$ Pa-s); temperature at which thermal stress is substantially relieved in a few minutes (~15 minutes).

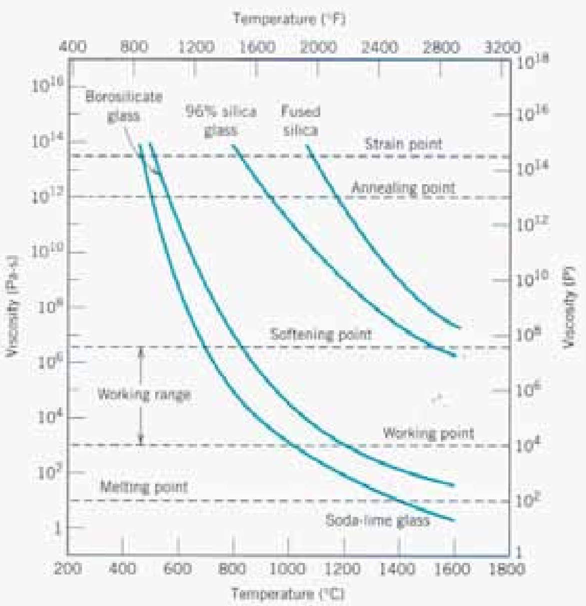
5. Strain Point: **(**η **=** $3 \cdot 10^{13}$ Pa-s); at the strain point temperature, thermal residual stress is substantially relieved in several hours.

Table 1

MATERIAL	*η (Pa-s)*
Water	.001
Blood or Kerosene	.01
Anti-Freeze or Ethylene Glycol	.015
Motor Oil SAE10 or Corn Oil	.050 to .100
Motor Oil SAE30 or Maple Syrup	.150 to .200
Motor Oil SAE40 or Castor Oil	.250 to .500
Motor Oil SAE60 or Glycerin	1 to 2
Corn Syrup or Honey	2 to 3
Blackstrap Molasses	5 to 10
Heinz Ketchup or French's Mustard	50 to 70
Tomato Paste or Peanut Butter	150 to 250
Shortening or Lard	1,000 to 2,000
Caulking Compound (tile grout)	5,000 to 10,000
Window Putty	100,000

Working Range is the temperature range between the working point and softening point

FIGURE 13.6
Logarithm of viscosity versus temperature for fused silica and three silica glasses. (From E. B. Shand, *Engineering Glass*, Modern Materials, Vol. 6, Academic Press, New York, 1968, p. 262.)



Brittleness and thermal stresses. Glass transition temperature.

At room temperature, glass is a brittle material. It is prone to failure by crack propagation. This limits the applicability of glass in design.

On the other hand, the brittleness of glass can be employed for waste glass granulation. Granules are easily produced due the susceptibility of glass to fracturing by crack propagation. For comparison, this method of granulation will not work for ductile materials such as metals because they are resistant to failure by crack propagation.

Waste glass granulation

This Glass Workshop is equipped with a glass imploder developed by Krysteline Ltd, www.krysteline.net as seen 7/12/07. Waste glass bottles and jars are broken (imploded) into relatively sharp-free granules.

The size distribution of the granulated glass (glass cullet) is:

Size < 2mm	22%
2 < Size < 6 mm	52%
Size > 6 mm	26%

Granulating glass by the imploder at UoB workshop.
Miss Thomi Argyroudi, MSc Civil Engineering student, March 2007

Glass granulation is an important step in glass recycling. Glass cullet is a useful and saleable commodity. It has many applications for road aggregates, water filtration, www.wrap.org.uk as seen 27/12/7, decorative bricks in construction industry (http://www.davidwatsonworks.com as seen 7/12/7)

Recent work at the glass workshop of University of Brighton is focused on construction blocks TinGlass™ made from waste glass cullet melted in a tin-plated steel can. A patent application is filled in by Business Services of University of Brighton in the course of work on MSc Product Innovation and Development project by Mr M Bataineh, 2006.

TinGlass™ Construction Bricks

Mechanical properties of glass at high temperatures. Glass transition temperature

What is a glass? It can be viewed as a liquid that has cooled to a solid state without crystallization and hence it is amorphous.

Upon cooling, a glass becomes more and more viscous in a continuous manner with decreasing temperature. For crystals to form, atoms must meet to bond and orient; if the material is viscous, it is difficult for atoms to move.

The temperature at which supercooled liquid silica is considered to have turned into a glass is called the **glass transition temperature**.

Below this temperature, the material is stiff and brittle; above this temperature the material is more rubbery.

The **glass transition temperature** is about 600C for soda - glass, see Fig 2.154 p 155 and Fig 2.133 p 142 of [3]

Thermal expansion, thermal stresses and annealing

Glass experiences thermal expansion when temperature rises. Thermal stresses develop when thermal expansion or contraction is constrained.

When glass is cooled the exterior layers cool quicker and they shrink more rapidly than the core layers. This creates thermal stresses that can break the glass if cooled too rapidly. Hence the need in glass annealing, see [1] pp. 438-439.

Annealing is the process of making the entire glass item uniformly hot and holding that temperature steady long enough to remove all stress caused from the manufacturing process. The annealing cycle also includes cooling down slow enough so as to not allow too much residual stresses to build back up.

Tempering Glass

Tempered glass is used for applications in which high strength is important; these include large doors, automobile windshields, and eyeglass lenses. In thermal tempering a glass sample is cooled at different rates, the outside or surface is cooled more rapidly in an oil bath leaving the inside still molten. On cooling to room temperature, a system of stresses develops in the sample as shown in the Figure 13.9 reproduced from [1]. The resistance to crack propagation of the glass sample is enhanced by the compressive residual surface stresses.

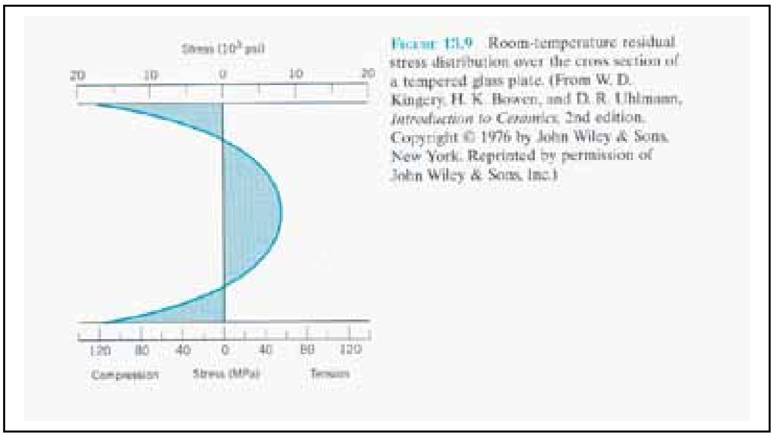


FIGURE 13.9 Room-temperature residual stress distribution over the cross section of a tempered glass plate. (From W. D. Kingery, H. K. Bowen, and D. R. Uhlmann, *Introduction to Ceramics*, 2nd edition. Copyright © 1976 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

<u>Experiment 1:</u>

Look at the glass sample in front of you. This glass was prepared starting from powder chemicals and melted at T > T_m . The melt was then cast into a preheated mould and it was soaking at the annealing temperature. The glass was annealed for hours and then slowly cooled down

.

Observe and feel the shape of the glass.

- Why is the edge thicker than the centre?
- Explain the thermal stresses present during the annealing

Optical properties: transparency of glass. Crystallinity and glass ceramics

Glass is an optical material, and more than anything else, it is defined by its transparency and colour.

Whilst the colour of a glass is associated with the chemical additives to glass, the concepts of crystallinity needs to be understood for transparency of glass.

<u>Crystalline and amorphous solids:</u>
[3], Section 2.5.3 p 152 ; Section 2.4.3 p 139; p 287

A *crystalline* structure is the one in which there is an orderly arrangement of molecules ; otherwise it is called *amorphous.*
For an example of relevance of crystal structure for the properties of a material, see diamond ***vs*** graphite [1].

Above the melting temperature, the material is liquid. If liquid silica SiO2 is cooled rapidly it is unable to get its atoms into an orderly arrangement required of a crystal. The resulting disorderly (amorphous) arrangement is called a glass. It is a transparent material.

Amorphous glass possesses no definite crystal structure (that is, no long-range order of the positions of the atoms). Since the light passes through it without absorption or scattering, it is a transparent material.

If melted silica is cooled slowly and some crystallization has occurred, this gives white translucent appearance of glass due to the scattering of light at the surfaces of crystal grains.

Glass ceramics is opaque; it is fine-grained polycrystalline material produced by a controlled crystallization of glasses. [1] p. 427

Energy-efficient glass processing techniques:
Laboratory demonstration of slumping and fusing of waste glass

After the introduction into glass properties and glass processing, we are equipped for the case study.

Case Study:
Collect several bottles and jars from your household, examine them and make suggestions for re-using or recycling them. Describe a range of products that can be made from them, and the techniques you are going to apply.

Essential Reading:

[1] *Materials Science and Engineering: AN INTRODUCTION*
Sixth Edition
William D Callister, Jr
2003 John Wiley & Sons, Inc.
ISBN 0-471-22471-5
All other editions of this textbook are suitable for the module

[2] *Design Engineering*
H.Cather, R.Morris, M.Philip, C. Rose
2001 Butterworth –Heinemann ISBN 0 7506 5211X

[3] *Technology of Engineering Materials*,
M. Philip and B Bolton
2002 Butterworth –Heinemann ISBN 0 7506 5643 3

[4] *Materials : engineering, science, processing and design*
Michael Ashby, Hugh Shercliff and David Cebon
Butterworth-Heinemann, 2007, ISBN 0750683910

[5] *Techniques of Kiln-formed glass,*
Keith Cummings, 2001 London : A & C Black,
ISBN 0 7136 6120 8

[6] *Introduction to glass fusing,* P. Kaiser, 2003 , Wardell,

ISBN 0-919985-38-6

Essential Reference:
Student Central, ME113
Level One Lectures on Manufacture by Dr Steve Plummer

Appendix 4

An extract from MSc Thesis by Mr I Lizarralde, SET, 2008

4.2.1 Exhibition at School of Architecture and Design,

The exhibition was organised by Dr Jyri Kermik, Technology Subject Area Leader of School of Architecture and Design, Faculty of Arts and Architecture. The exhibition was organised under the title ‘Material and its form’. This year it focused on uses of waste glass. This topic was set through collaboration between our two schools on waste glass recycling. Glass processing sessions and laboratory demonstration were held at the glass recycling workshop set at School of Environment and Technology at Cockcroft building. They were attended by the students of both Schools. The students of Faculty of Arts and Architecture have chosen an artistic angle whilst my study focuses on technical and commercial issues.

A poster exhibition was held showing the students' work and research. The research was based on different materials' utilisation and function. Some products were used and placed together creating new ideas. One of the developed materials was glass.

The aim of this visit was to get more ideas to develop a new product by regarding the research and work made by other students. There were some artistic examples of glass mixed with different materials using and playing with colours and shapes.

Also, it was possible to find a more imaginative mind from the work of other students with some very different materials that go further with the investigation and development of new mixed elements.

There was an example of glass mixed with concrete to be used in the architectural industry (Figure 8). Another example of glass utilisation was developed mixing with light creating an artistic product (Figure 9).

Figure 14 Material and its form exhibition example 1 by Mr Jeremy Diaper.

Figure 15 Material and its form exhibition example 2 by Mr Jeremy Diaper.