PROJECT NO: FP6-513166

SEPARATE

Eco-Efficient Designs for End-of-Life, Anti-Counterfeit Electronic Device Recovery

Co-operative Research (Craft)

Horizontal Research Activities Involving SMEs

Publishable Final Activity Report
Month 0 – Month 27

Date of issue of this report: 28th February 2007

Start Date:1st October 2004 Duration: 27 Months

Lead Contractor: Haswell Moulding Technologies Limited

Version 01

CONTENTS

1. PROJECT EXECUTION……………………………………………3

2. DISSEMINATION AND USE………………………………………8

1. PROJECT EXECUTION

This report covers the work carried out in the European Commission Framework 6 project ‘SEPARATE’. The overall industrial objective of the project is to develop a manufacturing process and cost effective recycling route in response to the European Commission’s Waste Electrical & Electronic Equipment (WEEE) Directive.

The primary target market for the ‘SEPARATE’ technology are high technology electro-polymeric consumer products with short life spans such as mobile phones, personal digital assistants (PDAs), digital cameras, toys and laptop computers. The secondary market includes contactless smartcards, RFID tags, mobile phone SIM cards and store loyalty cards, an alarming number of which enter the domestic waste stream.
This specific segment of the total WEEE market represents around 60% of WEEE products and 4.5 million tonnes per annum of waste.
The project has developed a complete suite of innovative processing and reclamation techniques, required to provide a closed loop product manufacturing system. This has been achieved by embedding the electronics in a water-soluble, biodegradable, polymer shell.

The technical work over the period 01/10/2004 to 31/12/2006 has been spread over the tasks in the following Work Packages:-

- WP 1: Enhancement of Scientific Understanding of Soluble Polymers
- WP 2: Creation of New Over Moulding Technological Capability to Create Electronic Modules
- WP 3: Development of a New Technological Capability to Semi-Encapsulate Electronic Modules
- WP 4: Industrial Validation

The activities in the ‘SEPARATE’ Project have been conducted by a consortium consisting of 8 organisations from 6 different European countries. The project has been coordinated by Haswell Moulding Technologies Ltd. These organisations are listed in the table below.

Role*	Participant No.	Participant Name	Participant Short Name	Country	Date Enter Project	Date Exit Project
CO	1	Haswell Moulding Technologies Ltd	Haswell	United Kingdom	Month 1	Month 27
CR	2	Mapro spol s.r.o	Mapro	Czech Republic	Month 1	Month 27
CR	3	PVAXX Research & Development	PVAXX	United Kingdom	Month 1	Month 27
CR	4	Uniteam-Italia S.R.L	Uniteam	Italy	Month 1	Month 27
CR	5	Novacard Informationssysteme GmbH	Novacard	Germany	Month 1	Month 27
CR	6	Rosti AS	Rosti	Denmark	Month 1	Month 27
CR	7	Pera Innovation Ltd	Pera	United Kingdom	Month 1	Month 27
CR	8	Technical Research Centre of Finland	VTT	Finland	Month 1	Month 27

*CO = Coordinator
CR = Contractor

The first step in the development of the 'SEPARATE' technology was to select a suitable water soluble polymer. Polyvinyl alcohol is a non-toxic, biodegradable, water soluble polymer. The performance properties of polyvinyl alcohol are influenced by molecular weight & the degree of hydrolysis. The degree of hydrolysis affects the water sensitivity and the degree of polymerisation determines the molecular weight and hence the processability.
Conventional polyvinyl alcohol cannot be processed by traditional injection moulding and extrusion technologies since it decomposes close to its melting point. However, the P2 grades of polyvinyl alcohol produced by PVAXX Research and Development Ltd, incorporate an internal plasticiser which enables the material to be injection moulded and extruded.
The versatility of base polyvinyl alcohol polymer plus PVAXX's patented formulation technology therefore enables the generation of injection moulding and extrusion grades, having a wide range of mechanical properties and water solubility characteristics.
The PVAXX range of existing formulations were characterised. Samples were injection moulded and mechanical & water solubility testing carried out. Grades most suitable for protected environments are low molecular weight and 88% hydrolysed PVOH's. These grades will give fast dissolution in hot water or steam. Such grades also benefit overmoulding, by lower processing temperatures and higher melt flow indices eliminating electronic component deformation. Grades most suitable for use in an unprotected environment would be of high molecular weight and high degree of hydrolysis, this would impart the maximum water resistance.
To withstand the effects of environmental humidity, yet provide rapid dissolution to be achieved specific water resistant coatings were identified that could be applied to the PVAXX overmoulding and removed prior to dissolution.

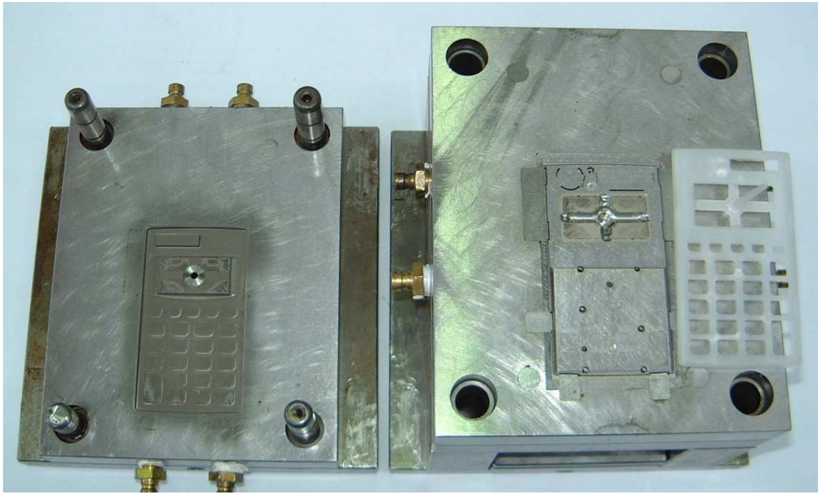
To achieve a target dissolution time of 30 seconds per electropolymeric component, a batch dissolution process was selected. Methods to accelerate dissolution were investigated, and it was demonstrated that the effect of ultrasonics significantly increased dissolution time.

It was then validated that the PVAXX polymer could be reused and injection moulded after being recovered from solution without significant degradation of properties. Elongation at break of the test pieces was slightly reduced, this being attributed to a small loss of plasticiser during the drying process. Additional plasticiser can be added to the recovered polymer to address this.

An injection mould tool was manufactured and fully encapsulated electronic modules for a smartcard application were produced. These were shown to be fully functional after overmoulding with PVAXX. Other fully and semi-encapsulated electronic case study components were then selected to represent the targeted market sectors. These included a contact & contactless smartcard, a memory stick and a calculator casing. A generic water soluble electronics fixing clip and mounting plate were also selected that could be used together or alone in all types of equipment requiring circuit board fixing.

Concept designs for the location of electronics, the injection moulding tooling and the over-moulding process with water-soluble polymer for smartcard applications were produced, and a CAD simulation of an incorporated high speed handling system for electronics placement was developed. An IGRIP simulation was made for a smartcard overmoulding process. IGRIP simulation enables evaluation of program and estimation for cycle times. The simulation of smart card moulding resulted in 6.7 seconds robot cycle time in total.
However, on review of the very tight tolerances & specifications involved during the manufacture of smartcards, it was decided by the Consortium that to demonstrate the 'SEPARATE' technology accurately & effectively for a smartcard application, the method of production be by a lamination route rather than by injection moulding. Extrusion trials were performed and water soluble PVAXX film manufactured. Lamination trials were performed by Novacard to produce fully functional contact & contactless cards.

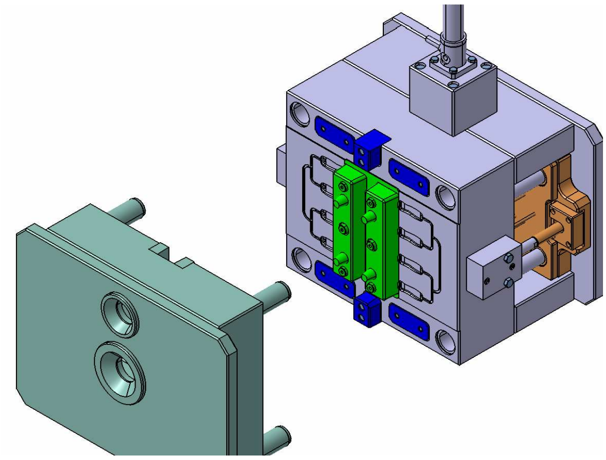
3D CAD designs were generated for a memory stick, a calculator casing, and a mounting plate & fixing clip case study components. Injection mould tools were designed and prototype tools manufactured for each component.



For the production of the overmoulded memory stick, Uniteam Italia SRL utilised their innovative 2-shot moulding technology. A 2 + 2 impression tool was designed and manufactured which would initially overmould a memory stick circuit board with water soluble PVAXX polymer, and then in a second stage this is overmoulded with a soft thermoplastic elastomer which provides a protective coating to the hydrophilic polymer. A window frame of PVAXX remains around the USB plug and around the hole at the end of the moulding, to allow for ingress of water, dissolution of the PVAXX and the separation and recovery of the recyclable thermoplastic elastomer casing and the electronics.

Memory stick circuit boards were overmoulded with PVAXX polymer and their functionality examined before the second overmoulding stage. It was established that the pressures involved in the injection moulding process and the flow pattern of polymer over the components on the circuit board could cause distortion of the board and damage to the electronics. It was established that foaming of the PVAXX polymer with a blowing agent significantly reduced the pressures involved & this was found to eliminate damage of the circuit boards. In addition, to prevent the moisture absorbed by the water soluble polymer from causing a short circuit on the circuit board, the boards were treated with a waterproof electronics conformal coating prior to encapsulation in PVAXX. Fully functional mouldings

were produced. However, after the second overmoulding with a soft thermoplastic elastomer, only a few of the memory sticks were still functional. It is anticipated that the heat from the second overmoulding reactivates the blowing agent in the PVAXX and causes damage to the circuit board. In an industrial manufacturing scale-up process Trexel's MuCell™ Technology would be utilised rather than a blowing agent and there would therefore be no reactivation & damage of the boards. MuCell™ Technology uses inexpensive, environmentally friendly supercritical fluid (SCFs) of atmospheric gases (CO_2 or N_2) as blowing agents, and the MuCell™ microcellular foam process produces evenly distributed and uniformly sized microscopic cells.
For an industrial process a multi-impression tool would be required for an efficient moulding process. A design for a production tool with multiple impressions was therefore produced by Uniteam Italia SRL, and a tool sequence demonstrated. A robotic simulation of the injection moulding, handling and subsequent testing of memory sticks was developed to demonstrate a production moulding cell. In the simulation, a cycle time of 9.223 seconds for four finished USB-sticks was achieved. This means that a production rate of 1560 overmoulded USB-stick per hour is possible with the selected 6DOF industrial robot for material removal/placement. The robot itself can be easily programmed for a fast start-up by teaching the same tag points with same speed parameters as in the simulation.



Injection moulding trials were performed to produce PVAXX calculator casings, and mounting plates & fixing clips. Calculators were reassembled using the PVAXX casing mouldings and all remained functional. All the case study components developed were then evaluated for their ease of dissolution, separation & recovery.

A prototype dissolution, separation and recovery system was designed combining the use of ultrasonics and ultrafiltration technologies.
The dissolution time for each component depended upon the thickness of PVAXX polymer and the water bath temperature. Using ultrasound power technology, typically at 25 Watts per litre, a tenfold increase in dissolution time was observed at 60℃. An 80 litre ultrasonic system was optimised to give an evenly distributed ultrasonic radiation field, to apply a uniform treatment to all surface areas. All the case study components were successfully separated into raw materials; the calculator in 4.5 minutes, and the thicker memory stick took 15 minutes to remove all the polyvinyl alcohol & expose the circuit board. This batch procedure can dissolve many case study components together, and hence can theoretically meet the original objective to dissolve each component in 30 seconds.

The task also investigated the recovery of the polyvinyl alcohol by ultrafiltration for possible re-use. Ultrafiltration is a membrane filtration technique used to concentrate molecular species from solution. Through trials it was established that polyvinyl alcohol could be concentrated up to 16% from solution using this method. However, during the ultrasonic

tests it was found that dissolution occurred even up to concentrations of 35% polyvinyl alcohol in water, therefore an ultrafiltration unit was not necessary after all for the separation system.
A simulation was performed to study the industrial scale operation, and a counter-current washing principle was selected to minimize the use of energy and fresh water.

In conclusion, the project has met the objectives to develop a complete suite of innovative processing and reclamation techniques, required to provide a closed loop product manufacturing system. The separation and recovery of electropolymeric case study components has been demonstrated. This has been achieved by semi or fully encapsulating the electronics in a water-soluble polymer, and the development of a disassembly system incorporating ultrasonics to accelerate dissolution, and hence separation and recovery.
The socio-economic impact of the 'SEPARATE' technology is that electropolymeric components manufacturered by this technology will address the WEEE Directive. This will reduce the quantities of electropolymeric waste being discarded in Europe, and reduce the environmental and health & safety impact of heavy metals and organic pollutants entering the waste stream.

For further details, contact:

Mr Geoff Haswell
Haswell Moulding Technologies Ltd, Unit 3, Rice Bridge Industrial Estate, Thorpe Le Soken, Essex, CO16 0HH, United Kingdom
Tel: +44 (0) 771 373 0373
E-mail: geoffhaswell@aol.com
Project website: http://pera.projectcoordinator.net/~separate

2. DISSEMINATION AND USE

2.1 Final Dissemination and Use Plan