PROJECT NO: FP6-512956

IMPACT-USS

Innovative Manufacturing Process for Added-value
Car Tyre re-Use into Safer Surfaces

Co-operative Research (Craft)

Horizontal Research Activities Involving SMEs

Publishable Final Activity Report
Month 0 – Month 27

Date of issue of this report: August 2007

Start Date:1st May 2005 Duration: 27 Months

Lead Contractor: Murfitts Industries Limited

Version 01

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1. PROJECT EXECUTION

This report covers the work carried out in the European Commission Framework 6 project 'IMPACT-USS', Innovative Manufacturing Process for Added-value Car Tyre re-Use into Safer Surfaces.

In Europe 3 million tonnes of used tyres are presently generated each year. Through the EC Landfill Directive 1999/31/EC the landfilling of whole tyres was banned in 2003 and since July 2006 it has become illegal to landfill even shredded tyres. However, only 75% of the tyres are recycled, generally in low-added value applications such as incineration with energy recovery.
The material in old tyres has for some time been used to produce impact absorbing surfaces in sports and playground applications, but the traditional wet pour systems require accurate mixing of hazardous chemicals on site and can this lead to variability of the final surface. This, and the fact that the chemicals typically cost 10 times as much as the recycled material, has meant that the work is only carried out by a minority of specialist contractors, effectively excluding the larger community of smaller building contractors.

An additional consequence of the old system is that the surfaces are only used in very-high risk applications; however, with 22,000 European citizens killed each year as a result of slips, trips and falls outside the home, there has been a clear need for an impact-absorbing surface that all contractors in the trade can handle.

The overall industrial objective of the project 'IMPACT-USS' was to develop a prototype manufacturing system for producing a pre-mixed, one part safety surfacing material in a format that can be sold to and used by general contractors and the DIY market.

The technological objectives of the work were to develop a protective surface that:

- Achieves OSHA friction value greater than 0.6 giving it a "very safe" status for pedestrian surfaces.
- Achieves a product cost of €20 per square metre for a thickness of 25mm which is less than half the cost of incumbent products.
- Maintains OSHA friction performance between -10 and +40℃.
- Achieves impact performance corresponding to critical fall height and maintains this between -10 and +40℃.
- Impact surface conforms to EN1177 standard
- Contains less than 15 % PU binder to maximise the use tyre recyclate which is the lowest cost most abundant component.
- Can be applied without the need for pre mixing and cures within 24 hours of application.
- Withstands weathering for at least ten years
- Has a shelf life of at least six months

The activities in the 'IMPACT-USS' Project have been conducted by a consortium consisting of 10 organisations from 4 different European countries. The project has been coordinated by Murfitts Industries Ltd. These organisations are listed in the table below.

Partic. Role*	Partic. no.	Participant name	Participant short name	Country	Date Enter Project	Date Exit Project
CO	1	Murfitts Industries Ltd	Murfitts	United Kingdom	Month 1	Month 27
CR	2	Minor Industriplast AS	Minor	Norway	Month 1	Month 27
CR	4	2KM GmbH	2KM	Germany	Month 1	Month 27
CR	5	Zakalady Mechanicize Wiromet SA	Wiromet	Poland	Month 1	Month 4
CR	6	Pikehaven Ltd	Pikehaven	United Kingdom	Month 1	Month 27
CR	7	Pera Innovation Ltd	Pera	United Kingdom	Month 1	Month 27
CR	8	The National Institute of Technology	TI	Norway	Month 1	Month 27
CR	11	IMS Supplies Ltd	IMS	United Kingdom	Month 4	Month 27
CR	12	Industrial Copolymers Ltd	ICL	United Kingdom	Month 10	Month 27
CR	13	Protective Packaging Ltd	Pro-pack	United Kingdom	Month 12	Month 27

*CO = Coordinator
CR = Contractor

The technical work programme and the main results achieved over the period 01/05/2005 to 31/07/2007are as follows:-

Work Package 1 – Enabling Knowledge of Polyurethane Chemistry, Rubber Crumb Geometry and Polyurethane/Rubber Crumb Interactions

The first stage in the development of the 'IMPACT-USS' technology was to review the field of polyurethane chemistry and characterise commercially available isocyanates, polyols and polyurethane prepolymers which would give the required properties to the premix and the final cured system. Prepolymers have reduced diisocyanate vapour pressure, thus lowering inhalation hazards, and have higher viscosities compared to diisocyanate monomers thus allowing better mixing efficiency and minimising settling. Methylene diphenyl diisocyanate (MDI) based prepolymers have the advantage of much improved freeze protection and reduced toxicity compared to toluene diisocyanate (TDI) systems.
One-component polyurethane prepolymers cure by reaction with atmospheric moisture or substrate moisture which reacts with the isocyanate group to form carbon dioxide and amines. The amine then reacts with another isocyanate to give urea linkages within the polymer. These reactions cure the polyurethane by building up the molecular weight until an elastomeric material is formed.
For the 'IMPACT-USS' technology, a moisture curing, flexible MDI based polyether prepolymer having good surface wetting and adhesive properties was selected.

The second stage was to investigate whether any particular tyre crumb particle size, size distribution, or bulk density provided optimum impact resistance properties.

Existing commercial wet-pour safety surfaces applied in public play areas usually consist of two layers; one a base layer of coarse approximately 20mm mesh black recycled tyre rubber crumb and a top layer of much finer EPDM rubber granules, both layers bound with a polyurethane resin. These safety surfaces laid by experienced contractors are expensive, typically costing about €60 per square metre for 1.2m Critical Fall Height protection.

The aim of 'IMPACT-USS' was to develop a lower cost single premixed product that when laid and compacted matched the performance of existing 2-layer systems.

Analogous to the behaviour of spheres there is an increase in density associated with the mixing of different particles sizes of similar shapes. However, volume expansion is sometimes observed in mixtures of irregular particles such as tyre crumb. It was concluded that optimal packing required a large particle size ratio, with values of D_{large}/D_{small} over 20 being most useful. Due to the limited particle size range available for rubber crumb, 0.5-6.0mm being most suitable for safety surfaces, it was not possible to develop a robust model. A tyre crumb mixture with a particle size ratio of 12 blended with prepolymer & cured supported a slightly higher peak load but differences in energy absorption were insignificant.

To provide a more aesthetic surface appearance to the 'IMPACT-USS' product and to avoid the settling of finer particles in a tyre crumb blend during storage, a 1-3mm product was selected.

Work Package 2 – Chemistry Development of Stable Pre-Mix

The compositions of tyre compounds were examined to identify the main constituents present which could adversely affect the stability of the polyurethane prepolymer. Tyre manufacturers each have their own proprietary formulations and therefore little information was available about the final compositions. However the most likely reactions to occur with the free isocyanate group were determined and methods to remove the most reactive impurities were investigated. Low boiling point plasticisers and amines could be removed by heating of the crumb, whilst elemental sulphur and zinc oxide were shown by Inductively Coupled Plasma Spectroscopy (ICP) to be significantly reduced by washing with distilled water.
Even though many compounds were present in tyre rubber crumb the availability for reaction with the prepolymer binder to contribute to premature curing was anticipated to be quite limited. Storage tests established that tyre crumb supplied directly from the granulation process cured the polyurethane prepolymer within 8 hours, whereas dried, untreated tyre crumb combined with the prepolymer remained stable in an airtight container in excess of six months, indicating that the moisture content of the tyre crumb was the most important factor. Storage tests carried out at elevated temperature established that a crumb moisture content of less than 0.3% by weight was required to provide sufficient stability.

Throughout the project the Consortium continued to explore alternative chemistries which would provide increased stability. The use of water-borne polyurethane dispersions (PUDs) were thought to provide an interesting alternative to the isocyanate based prepolymer traditionally used in the fabrication of rubber crumb surfaces. These water based dispersions have no isocyanate content and are generally very low hazard. Furthermore, these polymers cure by evaporation as opposed to moisture cure meaning that special packaging conditions were not needed and pre-drying of the rubber crumb was also not required.
Excellent tensile and impact absorption performance were achieved with the PUDs, but the longer curing and drying of such binders compared to prepolymers made them impractical.

Methods to improve bonding between rubber particle and prepolymer were explored, these included surface activation of the rubber particles by devulcanisation and copolymer grafting. However, due to cost restraints of the final product these were not pursued.

Work Package 3 – Development of Binder & Crumb Manufacturing Process

The next stage in the development of the 'IMPACT-USS' technology was to design and build a prototype manufacturing system capable of producing a minimum of 100 kg of premix. The individual stages of the prototype system were considered and the technologies available were reviewed and selected by the Consortium.

Infrared and desiccant drying were identified as suitable technologies to remove moisture in the tyre crumb to below 0.3%. Continuous rotary infrared drying systems would be the most suitable for a full-scale manufacturing process, capable of drying up to 1500kg of tyre crumb per hour. However, for the prototype, a batch desiccant system was developed with a separate carbon filter to protect the desiccant bed from volatile contaminants from the tyre crumb during the drying process.

To achieve dispersion and uniform distribution of the viscous prepolymer resin with the tyre crumb at high loadings of 85-90% by weight, continuous single screw mixing was selected. After some initial experiments with an existing Robson 0.5 metre screw conveyor, a 1.6 metre long single screw extruder with ribbon flighting and a cylindrical barrel configuration, was designed and manufactured. Tyre crumb was conveyed from the desiccant dryer to the mixer by a separate screw feeder, and predetermined amounts of prepolymer were delivered to the mixing chamber by a variable gear metering system. By tuning the mixing speed and component delivery rate, the residence time in the barrel was optimised to achieve the required premix homogeneity.

To minimise moisture uptake during the preparation of the premix, the conveying and mixing operations were performed under a circulating blanket of dry air.
A bagging station was designed and manufactured and sited at the exit of the extruder to allow premix to be dispensed directly into aluminium barrier foil packaging. To provide maximum product stability, this was purged with dry nitrogen before heat sealing in line.

To ensure maximum protection against water vapour and oxygen ingress a multilayer barrier material with increased aluminium content was selected for the 'IMPACT-USS' product. The thicker aluminium layer would also prevent pinholing during excessive flexing of the packaging, and a nylon layer was included in the formulation to provide improved puncture resistance.

To assess the long term stability of the product, the premix was stored in 25kg aluminium barrier foil bags at 40℃. The product remained st able for more than 3 months under these conditions. Application of the Arrhenius formula for the temperature dependence of a chemical reaction rate, indicated that the 'IMPACT-USS' product manufactured under prototype conditions would have a shelf life at 20°C of up to 12 months.

The completed and optimised prototype manufacturing system was demonstrated by the Consortium and 250 kg of premix was produced for field trials and samples.

Work Package 4 – Technology Validation

The Consortium demonstrated the ease of sub-surface preparation and application of the 'IMPACT-USS' product through field trials. Overnight curing occurred for even a 100mm thick section.
Test beds were analysed at a FIFA accredited laboratory. Tested in accordance with BS EN 1177 'Impact Absorbing Playground Surfacing – Safety Requirements and Test Methods:1998' a 50mm thick product gave a Critical Fall Height of 1.25m, comparable to existing two-layer wet-pour systems.

Slip resistance was measured in accordance with BS 7188:1998 'Impact absorbing playground surfacing – Performance requirements & test methods'. This is more appropriate to safety surfaces than the Occupational Safety and Health Administration (OSHA) static coefficient of friction recommendations.
BS 7188:1998 specifies that the minimum slip resistance under either wet or dry conditions, shall not be less than 40. For the 'IMPACT-USS' product the average value under wet conditions was 69, and under dry conditions was 90, therefore by far exceeding the requirements.

To assess whether any deterioration of the impact absorption properties occurred with time, the product was subjected to UV ageing for 1000 hours. Little change in the performance was observed. A successful field trial carried out at Pera Innovation Limited was monitored for wear resistance. No deterioration of the surface laid in a pedestrian walkway was observed over a 5 month period.

Application specifications have been included within a Technical Data Sheet and a Material Safety Data Sheet has been produced for the purpose of the COSHH Regulations.

Finally the Consortium has produced a cost analysis and are currently completing a business case. Based on the present analysis, a product cost of €20 per square metre for a thickness of 25mm is achievable.

The technical work programme has been successfully completed.

Conclusions

In conclusion, the project has met the objectives to develop a prototype manufacturing system for producing a pre-mixed, one part safety surfacing material in a format that can be sold to and used by general contractors and the DIY market. The 'IMPACT-USS' product manufactured by the prototype system has been shown to meet the following technological objectives:

- Achieves a slip resistance >> 40 under wet or dry conditions – meeting BS 7188:1998
- Meets the criteria for Critical Fall Height – conforming to the impact absorption properties specified in to BS EN1177:1998
- Contains less than 15 % PU binder to maximise the use tyre recyclate which is the lowest cost most abundant component.
- Can be applied without the need for pre mixing and cures within 24 hours of application.
- Withstands UV accelerated weathering for 1000 hours
- Achieves a product cost of €20 per square metre for a thickness of 25mm
- Has a shelf life of at least six months

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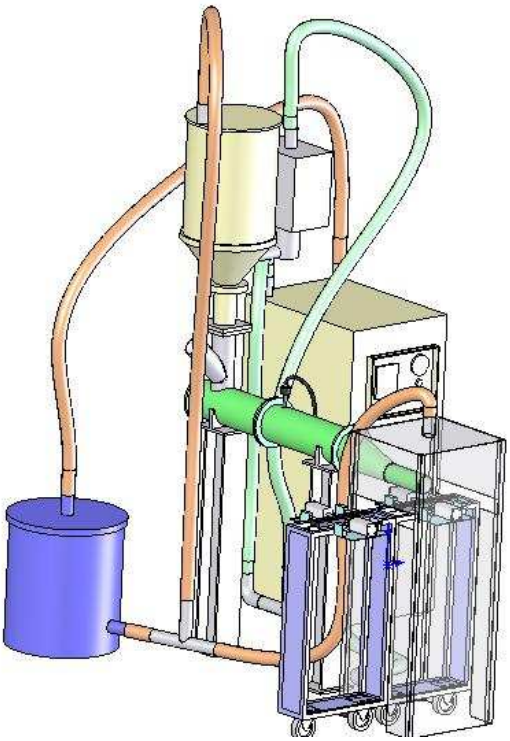
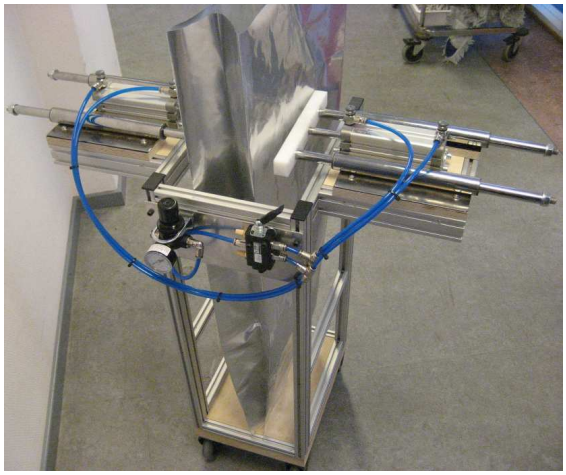
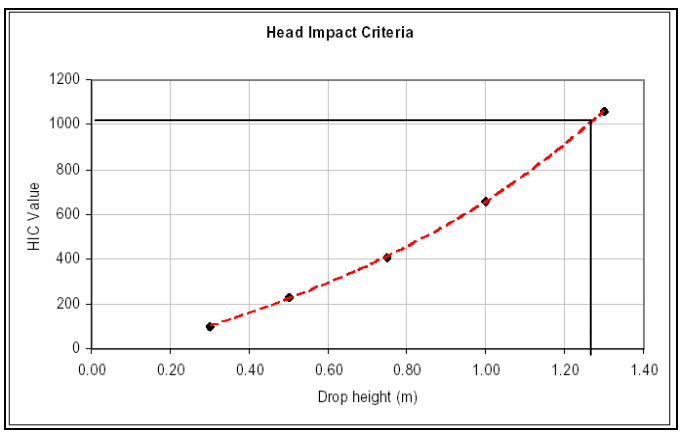
Project Images







2. DISSEMINATION AND USE

See Deliverable D22: Final Dissemination and Use Plan