Creating markets for recycled resources

Waste Tyres Case Study

Powdered Car Tyre Rubber in Replica Roof Slates

Product:	Composite rubber roof slates
Material:	Tyre derived rubber powder
Application:	Construction industry
Project Type:	Research & development into the use of an ultra-fine rubber powder/polymer composite material to produce replica roof slates.
Location:	Plymouth
Date:	Current

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Overview

The UK building industry is showing increasing demand for building materials which are more sustainable but which meet all current UK building standards and do not require new skills, tools or change of practice. The partners in the research and development (R&D) project described in this case study aimed to supply just such a product by developing a plastic-rubber compound, utilising a high proportion of recycled vulcanised rubber powder, for the manufacture of replica roofing slates.

Polymer-rubber compound replica roofing slates have existed for some time in the market place. None of these, however, are known to be presently manufactured in the UK, and therefore they do not contribute to utilisation of UK waste streams. Neither do they utilise significant portions of recycled vulcanised rubber powder or crumb in their compound.

In the first part of the case study, Airport Business Centre (ABC) designed and directed a programme in which Queen Mary University of London (QMUL) undertook laboratory trials to compound ultra-fine powdered rubber derived from post consumer tyres with recycled plastics to produce a moulded replica roofing slate. Subsequently ABC trialled a production mould to ensure that the combination of the compound and the production method selected could effectively produce the slate.

The project was successful in establishing the specification and production method to produce a composite replica slate. In principle this product is able to meet the requirements of the UK building industry at a cost which is competitive with natural slate and other synthetic roofing products.

Funding has now been awarded for a full certification programme, taking the product through standards certification to the erection of six demonstration roofs. The final phase will be commercialisation, in which a full market assessment will be carried out. Initial estimates are that the product will supply potentially 5% of the English slate roof market equating to 3,500 to 5,000 tonnes of rubber per year, depending on the thickness of the synthetic slate and the percentage rubber which can be incorporated into it.

Once the replica slate has undergone the in-situ trials, this R&D project is likely to lead to the set-up of a replica slate production business.

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Technical Information

Description	Units
Rubber particle size	Ultra-fine, 80 mesh (up to µm177)
Rubber content of tile	40% – 60%
Tensile modulus of tile	At least 850MPa
Strain at break of tile	At least 14MPa
Potential use of tyre-derived rubber	3,500 – 5,000 tpa
Equivalent used car tyre weight	5,700 to 8,200 tpa

Background

This case study examines both a novel raw material, a novel combination of raw materials, and an as-yet largely untapped end market in the UK. Whereas manufacturers do produce artificial slates which are composites of plastic, rubber and other constituents, they do not in general incorporate recyclate. This project aimed, where possible, to use only recycled materials or materials that would otherwise be waste.

Airport Business Centre (ABC) was formed in 2004 to develop businesses in four large factory facilities in Plymouth. One of the ABC Group wholly owned businesses is Crumb Rubber Ltd, which built and commissioned a new £2.3m rubber crumbing facility in Plymouth during the course of this research. The facility will provide ultra-fine vulcanised rubber powder, from used car and truck tyres, which has unique properties, with myriad surfaces providing greatly enhanced mechanical and chemical bonding potential. This raw material has not previously been available in significant commercial quantities and so its performance and behaviour in commercial composites is not well known or researched.

Market penetration of replica slates into the UK roofing market is small. In pre-project discussions, interest in marketing a UK produced slate made from recyclate was established with a significant wholesaler.

There is undoubtedly a growing demand from UK companies endeavouring to build more sustainably. The aim of this project was to produce a replica slate roofing tile to meet this growing demand. It is expected that features such as lightness, shatter resistance, durability, ease of fixing and aesthetic appeal should give this product an advantage over slate, and a good potential market.

Case Study

Benchmarking

A key part of this research and development project was to use, wherever possible, materials which are recycled or would otherwise be disposed of. Initially, recycled polypropylene (PP) and virgin high density polyethylene (HDPE) were separately melted and blended with ultra-fine car-tyre derived powdered rubber and wood flour. The resulting composite was extruded, pelletised and compression moulded to produce tiles which were then tested for physical properties.

As a guide to the suitability of various experimental treatments, an existing plastic/rubber composite replica roofing slate from a North American supplier was destructively analysed to establish base-line physical performance. This 'benchmark' tile contained approximately 20% by volume of rubber in a polyethylene matrix and had a tensile modulus (toughness) of approximately 850MPa at room temperature and a strength-at-break figure of 14MPa[1].

To achieve comparability with the 'benchmark' slate, the experimental composite blends were expected to achieve threshold values of:

- Approximately 850MPa tensile modulus at room temperature
- Approximately 14MPa strength-at-break
- 20% by volume rubber powder inclusion.

The tensile modulus and strength-at-break targets were not intended as definitive benchmarks of suitability of experimental compounds for the proposed application. These would be determined, at a later date, by testing replica slates made from the most promising blends against full industry-compliance standards. However, the rubber inclusion rate of no less than 20% by volume was proposed as a definitive and critical benchmark, since without at least this inclusion rate there would be no net improvement (above existing applications) in the recycling potential for rubber powder.

Testing the Composites

The composites were tested for stability at different processing temperatures. For wood flour or rubber powder to be successfully mixed into a thermoplastic polymer, they must survive without significant degradation at the polymer processing conditions, which are in turn determined by the melting temperature of the polymers under investigation (polypropylene and polyethylene). Trials showed that wood flour and powder rubber began to degrade at between 180^{o}C and 200^{o}C: indeed, at above 200^{o}C in trials, the extrudate generated smoke.

A processing temperature of 180^{o}C was chosen, below the range at which onset of filler degradation was seen, but above the melting temperature of polypropylene and polyethylene. It is noted that all polypropylene grades used in this investigation were coloured black. Polypropylene is usually a milky translucent colour so the recyclate must have contained some pigment - probably carbon black or a dye.

The physical properties of the blends were assessed by mechanical evaluation. After an initial blending trial of polyethylene and polypropylene with rubber powder it was seen that polypropylene was superior to the virgin polyethylene. Polyethylene was therefore excluded

[1] Tensile modulus is a measure of toughness, and strength-at-break is a measure of strength. In this instance they are both measured in megapascals, MPa. 1 MPa is equivalent to a pressure, or stress, of 1 million Newtons per square metre.

from the blending trial with wood flour.

The 80 mesh powder rubber, produced from milling whole car tyres, contains up to 35% carbon black as filler, with the remaining 65% consisting mainly of styrene-butadiene rubber (SBR) with small proportions of natural rubber (NR). The exact components are difficult to predict, as the powder is a composite not only of the various types of rubber found in the different elements of a tyre (tread, sidewall, shoulder, bead, liner), but also of various makes and brands of tyres. Typically, carbon black-filled NR and SBR is a 'low stiffness' material compared to polyethylene and polypropylene (Table 1), and will reduce the tensile modulus of the polymer blend.

Material	Measure	Modulus
Carbon black filled SBR and NR	Initial tensile modulus	1 MPa
Polyethylene (PE)	Tensile modulus	Approx. 1,100 MPa
Polypropylene (PP)	Tensile modulus	Approx. 1,100 MPa
Pine wood, in direction of grain	Bending modulus	Approx. 12,000 MPa

Table 1: Tensile modulus of the materials in the composite

All blends including both wood flour and rubber powder exhibited higher tensile modulus than the virgin (unblended) HDPE. All the blends of wood flour and polypropylene tested returned higher tensile modulus values than threshold. With blends including 0-20% by weight of powder rubber, tensile modulus values were generally higher than threshold, but blends above 20% by weight generally performed less well.

Analysis of Test Results on Composites

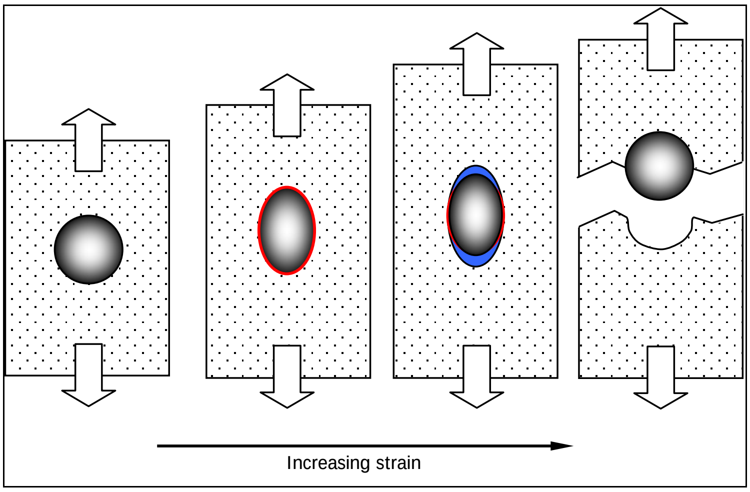
The project aimed to produce composite roofing slates with the highest possible rubber content while still possessing sufficient mechanical properties. The 'benchmark' slate was evaluated to have a loading of 20-30% by volume, or 17-25% by weight, of rubber powder. Blends tested in the laboratory were able to exceed this percentage loading of powder rubber while maintaining the same properties as those of the 'benchmark' slate.

The loading rate of 40-60% by weight of powder rubber is of particular interest to this project since the properties of polypropylene loaded with 40% powder rubber fall only slightly below the benchmark value.

The particular specification of polypropylene used had the best mechanical properties at high loadings of powder rubber and low loadings of wood flour, and was therefore taken forward for evaluation of all three components in a blend.

It has been hypothesised that the introduction of wood flour into the composite may "add value" by permitting the growth of lichens and moss on the finished product lending to a more "natural" looking roofing solution. However, it was seen that, although adding 20% by weight of wood flour into polypropylene alone gave a 107% increase in tensile modulus, in the presence of rubber powder there seems to be virtually no additional stiffening effect.

Adding wood flour to a system already heavily loaded with powder rubber leaves only a very small matrix fraction, and results of the tensile strength and strain at break tests suggests a poor adhesion between the wood flour and powder rubber to the polypropylene. The effects of this are shown schematically in Figure 1, which shows the composite material first unloaded then partially loaded, with interface failure and cavitation around the filler particle as the strain is increased, leading to ultimate failure of the composite.



Source: QMUL

Fig. 1: Diagram of breakdown of polymer matrix when loaded with foreign bodies

To avoid this failure of the composite, the effect of a commercially available polypropylene compatibilising co-polymer based on maleic anhydride was investigated. However, the compatibiliser appeared to be detrimental in all instances and to all properties. There were marked decreases in tensile strength and modulus and a slight increase in brittleness, when 10% by weight of the co-polymer was added.

Manufacturing test-run at QMUL

A replica slate measuring 380 x 250 x 5mm was manufactured using the knowledge gained from the various compounds produced. The maximum amount of rubber possible was melt blended into recycled polypropylene.

Polypropylene typically has a density of 0.95g/cm^3, and rubber has a typically density of between 1g/cm^3 and 1.3g/cm^{3,} depending on type and filler content. Using an approximate density of 1g/cm^3 for the blend, 540grams of material was compounded, corresponding to the volume of the mould plus 10% to account for any leakage and to ensure proper filling.

The compression mould was dosed with the compound and loaded into a press preheated to 200^{o}C. The mould was then left to soak at this temperature before being cooled to 50^{o}C under full pressure. The slate was de-moulded and visually examined for inclusions and other moulding defects. A blank polypropylene slate was also manufactured using the same procedure.

The moulded rubber-loaded slate looked very good, but as predicted from the tensile analysis of the blends was extremely "rubbery" with a low stiffness. It was therefore deemed necessary to re-visit options for stiffening the replica slate. As locally available wood flour and micaceous china clay failed to give the desired stiffness, glass fibres were tried as a conventional alternative[2].

The efficiency with which a fibre reinforces a matrix is related to the bonding between the fibre and the matrix and the bonding length, or fibre length. In this system brittle glass fibres were aggressively mixed into a polypropylene composite. However, the addition of the particular glass fibres used did little to stiffen the "rubbery", 60% powder rubber filled polypropylene slate.

Summary Results of the QMUL Trials

The results of the laboratory work show that the nominal bench mark properties adopted could readily be met at loadings of 20-30% by weight of rubber powder, and that loadings of up to 40% by weight produced a compound that showed good enough performance to warrant further commercial development for the proposed application. The recycled grade of polypropylene used in this investigation contains many unknowns which have unknown interactions with each of the investigated fillers. The use of virgin polypropylene may lead to more desirable properties as the composition of the base polymer is known and controlled.

Results suggest a rubber content of 40%, which is significantly greater than many other replica slate systems, should enable benchmark values for tensile strength and modulus to be achieved.

There is a change from benchmark properties as the percentage of rubber is increased from 40% to 60%. However, that does not necessarily rule out in practice the use of the higher rubber content composites. As a result, both 40% and 60% rubber content mixes were used in the production mould trials that followed.

Production moulding

The second part of this project was to trial production moulding to establish that the

[2] Note: the glass fibre used in this investigation, while not ideally suited to blending with polypropylene, was used as a "go, no-go" indicator for glass fibre stiffening of the 60wt% powder rubber filled composite.

compound(s) produced by QMUL's laboratory could be moulded satisfactorily, without insuperable production difficulties, to produce a replica roofing slate.

The trials at QMUL established that two blends of polypropylene and 40% and 60% ultra fine rubber powder provided properties close to the replica slate sourced from the US.

Further small scale lab trials produced satisfactory injection moulded swatches, indicating that this could be a viable production method for a full sized slate. A simple compression mould was constructed and trialled at QMUL. While this was not a standard slate size, due to the limitations of the moulding machinery available, and had no 3D profiling, it was sufficiently large to demonstrate that no great flow difficulties would attach to moulding roofing slate shapes using either compression or injection techniques.

A desk top analysis was undertaken to compare the relative likely merits in production of the different available moulding technologies. These were compression moulding, injection moulding, and extrusion. Mould costs, cycle times, accuracy, consistency, the ability to optimise the process such as to achieve flatness or a slight convexity in the slate, and aesthetic finish were all considered. Advice was sought from industry experts.

Results of the desk top study suggested injection moulding provides the best production method to take forward to trial. While injection mould costs are higher than for compression moulds, cycle times can be considerably shorter, thereby increasing potential productivity. The injection moulding process would also appear to offer better flexibility in optimising the slate in such respects as using flow lines as part of surface patterning to replicating the aesthetic finish of a natural slate.

A selection of full size standard natural slates (500 x 250 x 5 mm) was purchased from which one was chosen on grounds of ease of production – i.e. no overhangs in riven edges - and good looks. A 3D image of this was created for use by the toolmaker, C S Precision Ltd of Bodmin, Cornwall. A range of suggested options emerged as to the placing of injection ports and runners, flow of material in the mould, methods of achieving satisfactory 3D replication of the slate surface, etc. A full sized production mould with three hot runners feeding to the top edge was chosen (Figure 2).

Fig. 2: Injection mould tool in-situ, open

Compounding of a sufficient quantity of black recycled polypropylene and 80 mesh powder rubber was carried out at Eindhoven University under the direction of QMUL. Moulding trials were carried out at Inject Plastics Ltd of Totnes in Devon, as arranged by C S Precision Ltd, using a 330 tonne machine (Figure 3).

Fig. 3: Moulding machine at Inject Plastics Ltd

A number of mouldings were made from the two batches of compound, at 40% rubber and 60% rubber mix. As expected the 40% crumb replica slates were stiffer than the 60% powder slates, but other than that there was little visible difference and both mouldings were a good copy of the original slate (Figure 4).

Fig. 4: The first moulding run

Commercialisation

This project has successfully shown that ultra-fine 80 mesh rubber powder derived from post consumer car tyres can be combined with post consumer plastics, in this instance polypropylene, to produce a mouldable composite suitable for a replica roofing slate. Production moulding should present no special difficulties. An attractive black slate has been produced.

Fig. 5: Injection moulded 40wt% rubber-PP composite replica roofing slate

Myriad adjustments to temperature, pressure, dwell time, colour, flame retardant and stiffener are possible to optimise the slate for market requirements.

The next step is to commercialise the slate, starting with market research to identify precisely the segment of the roofing market best suited to this product. This will also inform decisions regarding the aesthetic requirements of the replica slate.

Commercialisation will involve taking the slate through a battery of tests in order to achieve the certifications needed for the UK market. Of particular importance to architects, planners and the building industry is flame spread BS 476 part 3, and British Board of Agrément certification. Certification should cover:

- Moisture absorption
- Freeze/thaw cycling
- Water permeation
- Accelerated UV exposure
- Fire rating
- Hail impact
- Wind driven rain in deployment
- Nail pull through
- Nail tear strength
- Heat cycling.

As the replica slate is significantly lighter than the natural slate it was moulded from (0.5Kg compared with 2.0 kg) it is also important to take account of wind effects such as lift and flutter at differing roof pitches. This may influence the type of nail used and other fixing protocols. It is also possible to introduce slight curvature in the slate so that nailing provides a positive down pressure at the exposed edges.

A successful application has been made to WRAP under TYR0017 'Construction Applications' for the commercialisation of this product and work to take it forward into that next stage can commence following the completion of this R&D stage of the project.

Health and Safety

While the smell of tyre rubber and plastic caused was not a problem during the production trial, some fume extraction could be advisable in full production.

Environmental benefits

One of the main aims of this case study was to prove the ability to manufacture replica roofing slates from 100% UK recycled materials. Once fully tested and commercialised, this product will meet the demand for more sustainable construction products. Initial estimates are that the product could supply 5% of the English slate roof market, equating to 3,500 to 5,000 tonnes rubber per year.

It is not easy to relate weight of rubber consumed to tyre units, because the tyre type greatly influences the weight: however, a car tyre is normally taken as being 7-8kg, and when fully processed, the average tyre produces about 61% of its weight in rubber granulate or powder. Hence the use of 3,500-5,000 tonnes of rubber equates to between 5,700 and 8,200 tonnes of used car tyres per year.

Technical Benefits

The replica slate produced in this case study was one quarter the weight of an equivalent natural slate: this lightness will allow lighter roof structures and ease of handling. Toughness makes the synthetic slates virtually unbreakable, reducing transit and site damage, as well as reducing fixing costs as they are simple to nail through without pre-drilling. They also look very like natural slate (and this property will be worked on further in the commercialisation phase).

Cost Benefits

Production costs are estimated to be half those of a natural slate, and lower than those of other synthetic slate products. The product looks better than imported rubber composite tiles and slates. In addition because the replica is a direct copy of a standard natural slate, it can be fixed exactly as a natural slate, without any requirement for skills training, new tools, techniques or systems.

Supply chain

Coarse shredded car tyre rubber is converted to an ultra fine powder through an ambient grinding process by Crumb Rubber Ltd of Plymouth, a subsidiary of Airport Business Centre. Crumb Rubber Ltd is now commissioning a new crumbing plant.

At present the shredded car tyres are sourced locally.

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Details of Parties

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