An Introduction to Recycled Glass As an Industrial Abrasive in the UK

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1. Summary

This report introduces recycled glass grit as an alternative industrial abrasive for shot blast use in the UK and includes technical performance information from work completed in the US by the Clean Washington Centre (CWC), and initial laboratory testing of industrial abrasives manufactured from post consumer recycled glass in Scotland. The available technical data and qualitative data from initial Scottish trials indicate that in many instances, recycled glass grit performs equally well and potentially better than existing abrasives as a cost competitive alternative.

Research completed in the US, highlighted copper slag as the primary conventional expendable abrasive that can be successfully replaced by recycled glass grit. Therefore, it is used as the basis for comparative assessment and testing of glass grit. Glass Grit samples were distributed to Scottish shot blast contractors for trial and qualitative data was collected regarding its performance. Additionally, initial laboratory trials were conducted by Remade Scotland, which validated earlier US findings about the performance of recycled glass as an abrasive, using locally processed glass.

The glass grit abrasive for the Scottish trials was sourced from Mac Glass Ltd, a company based in Dalkeith, who supply highly processed recycled glass for a number of alternative and innovative applications, including industrial abrasives.

The laboratory tests examined the performance of glass grit at three blasting pressures of 30, 50 and 70 psi (higher pressures may be used in typical shot blast work) on a small steel test surface contained within a blast cabinet. Objective third party analysis of the cleaned surface was carried out by (Ervin Amasteel) - an independent laboratory.

Previous research has indicated that due to the chemical composition and physical nature of glass, it has inherent advantages over more commonly used industrial abrasives, and the results obtained in this study seem to support this. The laboratory trial demonstrated that on mild steel, glass grit is capable of producing a surface cleanliness Sa3 with a fine to medium surface profile. In the trial conditions the copper slag took more than twice as long, used almost 5 times as much material by weight and cost approximately 3 times as much as the glass grit.

2. Introduction

2.1 Remade Scotland

It is often the case that recycling programmes struggle or fail to be successful due to a lack of supporting infrastructure, demand for the end product and the consequential higher cost of recyclate. Remade Scotland is a three-year initiative, which aims to stimulate and develop markets for recycled materials in Scotland as part of a wider programme of investment in recycling.

The Remade programme seeks to utilise expertise and experience, originating from the Clean Washington Centre (CWC), to identify potential markets for recyclate materials, where they can displace a primary and often non-renewable resource. The approach is material specific, with strategies being developed for priority materials such as glass, paper/pulp, organic waste, wood waste and plastics. It seeks to strengthen, stimulate and develop recyclate markets in Scotland in which the material can compete, not only on performance, but also on a cost benefit basis. More details of the REMADE programme can be found at www.remade.org.uk

2.2 Glass Recycling in Scotland

In Scotland there are approximately 225,000 tonnes of glass generated per annum, of which approximately only 15% is currently recycled. However, as a consequence of increasing recovery targets from the packaging waste regulations and the development of Local Authority waste plans required under the National Waste Strategy, the amount recovered is due to increase.

Most of the glass recycled is currently sent to the re-melt industry, where there are many benefits to using recycled glass in place of virgin materials, such as energy savings, cleaner emissions and the reduction of raw material usage. However in the UK there has been a historical oversupply of green glass, caused largely by net imports of wine and beer bottles. Further, it is believed that the bottle manufacturing industry is at or near its capacity to utilise recycled glass cullet in the production of new containers, and that as additional glass is collected for recycling, it will result in greater supply surpluses and therefore new alternative markets must be developed. In the development of the American market for recycled glass, the CWC identified three main alternatives to the re-melt sector:

- Granular products:
  - Industrial abrasives
  - Filtration media
- Construction aggregates
- Various other value-added products:
  - Tiles & architectural products (Fig. 1)
  - Bricks & concrete products
  - Terrazzo flooring

Figure 1: Decorative Tiles

This report focuses on the industrial abrasive application for recycled glass and complements earlier work carried out by CWC. The report also examines some comparative evaluation undertaken in the UK, and quantifies the UK market for industrial abrasives.

2.3 Suitability

Surface cleaning in the shot-blast industry has traditionally involved using sand, cast steel shot and various grits. However, recent studies have suggested that due to its physical nature, glass grit used as a shot-blast abrasive can have inherent advantages over more traditionally used abrasives. Advantages include:

- Glass particles are angular to sub-angular in geometry giving them the ability to cut/clean many coatings exceptionally well
- Glass particles have a light colour and can produce a "white metal" finish, which may be superior to other abrasives. It may also improve usability in low light environments
- Glass does not contain significant chlorides or other salts, which can accelerate corrosion of the cleaned surfaces
- Due to its inert composition and colour, the dust generated during use is less of a nuisance to the operating environment when compared to other abrasives
- Due to its physical nature glass may leave less surface residue and embedment, hence reducing cleanup costs
- Glass may produce an excellent surface profile adequate for many industrial painting applications
- Glass particles may be reused more times than other expendable abrasives
- With glass having a lower density than some other abrasives, a greater volume per weight will be produced, thus increasing productivity i.e. more particles directed at surface per given weight
- Unlike slag-based materials, glass essentially contains no heavy metals, thereby minimizing exposure to contaminants during operation, and reducing environmental contamination when the material is discarded
- When blasting outdoors where recovery of spent abrasive may be difficult, the benign nature of glass greatly reduces environmental pollution, which is of particular concern in or near sensitive water courses, as stated in the Scottish Environmental Protection Agencies (SEPA's) Pollution Prevention Guidelines 23: Maintenance of Structures Over Water.
- Since all copper slag is imported into the UK, there is a significant amount of pollution and cost generated from transportation. However, as glass can potentially be sourced locally, the pollution from transport can be greatly reduced, and also the industry has the opportunity to utilise a valuable local resource thereby supporting the local economy.
- Unlike sand, glass essentially contains no 'free-silica', which greatly reduces the threat of silicosis

3. Market Research

3.1 Market Structure

Market research by Remade Scotland showed that a few large companies such as USF Vacu-blast and Wolverhampton Abrasives etc. dominate the UK market, and they either produce the abrasive themselves, or buy in bulk from more specialist suppliers. The abrasive is then sold on by regional distributors (Appendix 9).

Shot blast contractors fall into two categories:

- **Small local contractors, with consumer type customers** – very small companies with a small workforce (~5 people), who tend to local or niche markets such as painting applications or component cleaning.
- **Large industrial contractors** – large companies who work extensively with industrial steel as part of their core business, and require shot blasting to complement their work. Organisations such as the Ministry of Defence (M.O.D), and oil exploration companies fall into this category.

Both markets have similar requirements in that they demand a consistently high performance from their abrasive, at an economical price. They also require sufficient quantities of material to be readily available to them, with adequate technical customer support.

There are two main categories of shot blast abrasive, expendable and non-expendable:

- **Expendable abrasives** are by-and-large for single use. The abrasive is either soft and breaks down quickly, or it is to be used for an outdoor application where there is little or no opportunity for recovery. Examples of expendable abrasives are: copper slag, glass bead, garnet, olivine and even walnut shells. Glass grit is deemed to be an expendable abrasive.
- **Non-expendable abrasives** are typically metal grits such as iron and steel, and they can be reused many times before becoming spent. These abrasives tend to be used indoors where the material can easily be recovered. They can also be used in blast cabinets where they will go through the system many times before being replaced.

3.2 Conventional Expendable Abrasive Markets

- **Copper slag -** Copper slag was deemed to be the main market for which glass grit could provide a competitive substitute. Recently, the last copper foundry in the UK was closed, and all copper slag abrasive is now imported into the country. Copper slag products vary in colour, contain carbon and may contain traces of other heavy metals in addition to copper. Some local authorities require copper slag to be disposed of as special waste after use.
- **Glass beads –** There is an existing specialty market for glass bead abrasive, where glass grit may be able to compete in some applications. Glass beads can be manufactured from recycled plate glass and are highly spherical in geometry. They can be used on sensitive surfaces such as aluminium, stone or stainless steel to achieve surface cleaning without damaging the substrate.
- **Other Expendable Abrasives –** There are several other expendable abrasives sold and used in the UK today that may be successfully substituted with recycled glass grit, these include: aluminium oxides, garnet, olivine, plastics, walnut shells and other specialty materials.

3.3 Market Size

Recent market research has indicated that approximate market sizes and prices in the UK, are as follows:

Table 1: UK market sizes & pricing

Abrasive Type	Market Size (T/Year)	Potential for Glass Grit Substitution	Potential Glass Grit Market (T/Year)	Price (£/T)
Copper Slag	100,000	90%	90,000	85
Glass Bead	10-15,000	20%	3,000	600
Other Expendables	50,000	25%	12,500	120
Total Market & Average Price			105,500	103.75

The figures in table 1 are approximate, and are referred to only as a guide.

The UK market is widely thought to be up to six times that of the Scottish market.

Over the past few years, there has been a large decline in the expendable abrasives market in the UK, which is normally around 400,000 tonnes per year. This is largely due to a change in trend of the workforce, from a heavy engineering industry to an electronic/finance-based economy. Further to this, vast technological improvements in water-jet blasting have also had an impact on the market.

The smaller shot-blasting contractors, of which there are approximately fifty in Scotland, typically use between 50 to 100 tonnes of expendable abrasives each year, which represents a total consumption of between 2,500 and 5,000 tonnes per annum, with an additional 15,000 to 25,000 tonnes per annum being used by the larger companies.

The price per tonne of the abrasive depends on the type, quantity purchased and the proximity to the supplier.

From the above figures, the Scottish copper slag market is estimated at being between 1 and 2 million pounds per annum, with the glass bead market being approximately £1.5 million.

The UK market turnover for copper slag is approximately £8.5 million with glass bead accounting for approximately £9 million.

4. Performance Assessments

4.1 Clean Washington Centre

In 1998, the Clean Washington Centre in Seattle completed a technical report[1] documenting comparative testing of recycled crushed glass grit for shot-blasting purposes, comparing it to more traditional slag based abrasives.

The trials involved using mixtures of post-consumer bottle glass and post-industrial plate glass, and comparing them to both nickel and copper slag abrasives. The abrasives were initially tested on mill scale, however once the project was underway the testing was modified to focus primarily on coated steel.

The results (Table 2) showed that there are many factors which affect the productivity of a given shot-blast abrasive such as the blasting pressure, the metering rate, the nozzle size, and so on. These variables all play a key role in the cleaning efficiency of an abrasive, and highlight the fact that there is a complex trade off between the consumption rate of an abrasive and the cleaning rate, when calculating the overall cost of the project.

During the trial the copper slag produced the least amount of dust, with the glass grit generating slightly more, however the nickel slag was the worst offender. Although dust was produced using these abrasives, it was demonstrated that the shot-blast technician could somewhat control the amount of dust generated by varying some of the parameters such as the blast pressure, metering rate and nozzle size etc.

The glass grit successfully removed hard coatings such as epoxy and enamel from steel, whilst producing a surface profile suitable for recoating purposes, therefore the trial demonstrated that crushed glass abrasive could easily compete with slag abrasives with regards to performance.

The trial also highlighted that due to the many variables involved, shot-blasting is as much an art as it is a science, and therefore to gain the maximum efficiency from an abrasive, both with regard to performance and cost effectiveness, time should be taken to experiment with the medium to find its optimum parameters.

Table 2: CWC comparative abrasive test results

Test No.	Abrasive	Grit Size	Nozzle Blast Pressure (psi)	Coating Type	Coating Thickness (mils)	Cleaning Rate Ft^2/Hr	Consumption Rate		Surface Profile (mils)	Cost $/ft^2
							lbs/hr	lbs/ ft^2		
37	VitroGrit	#40	100	Epoxy	>15	125	1048	8.38	4.1, 3.6	0.63
38	VitroGrit	#40	100	Coal Tar Epoxy	6 – 8	106	1091	10.35	3.1	0.76
39	VitroGrit	#40	100	Millscale	~1 – 2 est	144	970	6.76	2.5	0.51
36	Kleen Blast	#30/60	100	Epoxy	>15	102	1598	15.72	4.0, 3.7	1.07
34	Kleen Blast	#35	100	Epoxy	>15	109	977	8.98	3.6	0.68
35	Kleen Blast	#35	100	Coal Tar Epoxy	6 – 8	89	900	10.1	3.6	0.79
24*	Kleen Blast	#35&#16/30	100	Epoxy	>15	68.7	1103	16.1	4.4	1.18
25*	Kleen Blast	#35&#16/30	100	Epoxy	>15	57.9	1103	19.1	4.0	1.41
26	Green Diamond	#3060	100	Epoxy	>15	86.3	1314	15.23	4.0	1.08
27	Green Diamond	#3060	100	Epoxy	>15	71.0	928	13.1	3.8	1.01
29	Green Diamond	#3060	100	Alkyd	5 - 10	40.7	768	18.9	3.0	1.54

Substrate for All Tests = Steel
Note: Tests marked with "*" are anomalous; see test form
Kleen Blast is a copper slag abrasive, Green Diamond is nickel slag and Vitro Grit is a glass grit abrasive

[1] CWC - Testing and Certification of Industrial Abrasives Manufactured From Recycled Glass

4.2 Initial Scottish Trials

Following an initial desktop/telephone survey, a workshop was held on 19th October 1999 by Remade Scotland, aimed at stimulating interest in alternative applications for recycled glass in Scotland. The workshop was used to introduce information about the use of recycled glass in a number of applications including shot blasting, and was attended by a principal supplier of glass grit and several shot-blast contractors. Based on the initial survey and workshop feedback, six shot-blasting contractors of various size and fields of expertise were identified, and were engaged in trying the glass grit abrasive in place of their more conventional abrasive.

For the purpose of this initial study, each contractor was supplied with 50kg of each grade of glass grit:

- Fine (0.09mm – 0.25mm)
- Medium (0.4mm – 0.6mm)
- Coarse (0.6mm – 1.12mm)

The glass grit for these trials was sourced from Mac Glass Ltd. of Dalkeith, Scotland.

On delivery of the material, each contractor received some suggestions on how best to utilise the abrasive, however other than that they were given full licence as to how they used the material.

A follow-up survey of each participating contractor revealed positive qualitative feedback regarding the performance of the glass grit. The results indicated that the glass grit was able to compete performance-wise with copper slag and olivine sand, however the glass grit was unable to compete fully with glass bead, although it was identified as being able to replace it or be used in conjunction with it in certain applications.

Figure 2: Blast cabinet

Another benefit of using the glass grit highlighted during the trials was that due to glass grit being impervious and non-hydroscopic, the performance did not seem to be as adversely affected by dampness, as is the case with copper slag. Also, leaching did not seem to be a problem with the glass.

Although these trials were deemed successful, they highlighted the need for further technical information regarding the optimum performance parameters. The follow-up survey also confirmed that not only were the contractors concerned with performance, but that they were also highly focused on the cost, therefore willingness to pay more for a medium that offered performance advantages was judged to be minimal.

4.3 Laboratory Evaluation

Remade Scotland in conjunction with the Business Environmental Partnership undertook a laboratory comparison of recycled glass grit abrasive, copper slag and glass bead.

The laboratory trial concentrated on the cleaning of mild steel surfaces and masonry (sandstone blocks), which were highlighted as key applications. The glass grit used during the trial was 0.2 - 0.6mm.

The trials were performed within a controlled environment, using facilities at Kvaerner Energy Ltd in Glasgow, a heavy industrial manufacturing plant.

Supplier

The glass grit for the trial was again sourced from Mac Glass Recycling, an accredited reprocessor with many years experience.

Laboratory Equipment

The trials were performed in a Tilghman Wheelabrator blast cabinet (Fig.2) fitted with a half-inch nozzle. The cabinet helped to keep many of the parameters constant, which was deemed necessary for final analysis.

As the blast cabinet was set up for recycling the abrasive, steel plates were made and fitted into the bottom of the cabinet, in order to collect the material after blasting for further analysis. Once each medium had been tested, the blast cabinet was emptied to avoid cross contamination of abrasive (Fig.3).

Test Surface

The surfaces cleaned were oxidised mild steel, and sandstone with pollution staining. The steel plates were $1ft^2$, consistent in size and shape and were sourced on site

at the Kvaerner plant.

The sandstone blocks were varied in shape, and therefore no definitive results were expected. However the results did provide enough information to give a positive indicator of performance.

PSD Analysis

The trials involved an initial Particle Size Distribution (PSD) analysis before blasting; this was done using an Endecotts EPL 2mp3 test sieve shaker with Mettler Toledo SB12001 electronic scales. Results of this analysis are shown in Appendices 2, 3 and 4.

Figure 3: Emptying Cabinet

Test Parameters

After consulting prominent shot-blast abrasive suppliers in the UK, blast pressures of 30, 50 and 70psi were used, as these were deemed satisfactory for use in blast cabinets at a distance of 18 inches. The pressures were carefully selected to demonstrate the change in performance with change in pressure, however it must be noted that these pressures were chosen for use in a blast cabinet, if blasting out-with a cabinet, higher pressures would normally be used, as the nozzle to surface distance would be increased.

Each test was timed; the spent material collected, and a further PSD analysis was performed to determine the breakdown of the material, again using the same equipment as before (Appendices 2, 3 and 4).

Surface Evaluation

Once blasting was completed, the cleaned plates were collected and sent to Ervin Amasteel in Tipton, where they performed a surface evaluation, measuring both surface cleanliness and surface profile. This was performed using a Taylor Hobson Surtronic 3P stylus instrument (see Appendix 6).

Cost Considerations

Some basic cost calculations were made, however they do not take into account such variables as cost of labour, energy and wear and tear of equipment etc. as these are independent of abrasive type.

During the trial, the glass grit proved to be by far the most cost effective of the three abrasives. This was largely due to the fact that less glass grit abrasive was required to clean the given surface than its competitors (see Appendices 5 & 7).

Also, with the clean nature of the dust generated during blasting the cleanup costs of a project can be reduced.

Another benefit of glass grit is that since it has a lower specific gravity than many other abrasives, it yields more medium per given weight than other heavier abrasives, which again adds a cost benefit.

Findings

The trial demonstrated that the glass grit was very effective in these applications, cleaning to a high standard, and on a performance basis could easily compete with the copper slag.

The trial highlighted many advantages to using glass grit such as:

- It could yield up to 2 to 3 cycles before becoming ‘spent’ depending on the application
- The cleaning rate was higher than that of the copper slag
- The glass grit took the least amount of medium to clean a given surface, which is not only a cost saving factor to the contractor when purchasing the material, but also when taking into account the clean-up costs of the project
- It cleaned the surface to a very high standard (Sa3), producing a ‘white metal’ finish
- It produced a fine to medium (23 to 70 microns) surface profile on the mild steel plates, adequate for re-coating purposes
- The dust produced by the glass grit was of a clean nature, when compared to the dark chalk-like residue left behind by the copper slag, it therefore did not tarnish the colour of the blasted surface, again reducing clean-up costs
- As various grades of glass grit can be produced, the medium can almost be tailor-made to meet any specification
- It can be mixed with other abrasives such as glass bead or water to produce a specific finish
- The glass grit cleaned the masonry to a very high standard without unduly eroding the surface, which is a major factor in this application

Figure 4: Oxidised plate before blasting

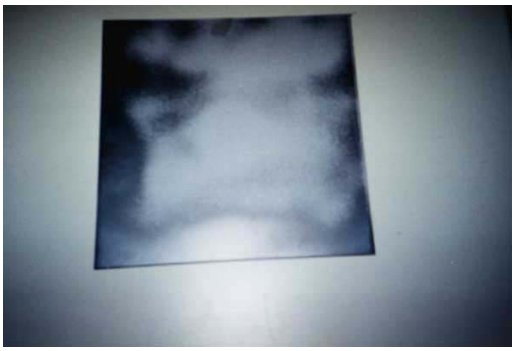


Figure 5: Plate cleaned by Glass Grit

Figures 4 & 5 demonstrate the effectiveness of the glass grit, effectively removing the impurity on the surface whilst cleaning to a very high standard.

Conclusion

During the trial, the glass grit outperformed the copper slag comprehensively in both performance and cost effectiveness. The trials demonstrated that on mild steel that glass grit is capable of producing a surface cleanliness of Sa3, with a fine to medium surface profile.

In the trial conditions the copper slag took more than twice as long, used almost 5 times as much medium (by weight) and cost approximately 3 times as much as the glass grit.

With environmental legislation becoming increasingly stringent, companies are looking for ways in which to demonstrate their commitment to the environment. As in many cases, the shot-blast industry works to very tight profit margins and as such cannot afford to risk fines imposed on them by the environmental governing bodies, therefore environmentally benign abrasives such as glass grit should be used where possible.

The glass grit used was 0.2 to 0.6mm in size, however previous trials have shown that a 1.12mm minus glass grit would perform equally well in many applications. This requires less processing and therefore significantly reduces the manufacturing costs. However, with the unique characteristics of glass, coupled with improvements in glass processing technology, the glass grit can be processed to meet almost any specification.

The glass grit worked quickly, producing a high quality finish with the pressures tested. Within the industry there is a general consensus that blasting be at as high a pressure as possible in order to finish the project quickly, however findings have shown that improved results may be achieved by carefully adjusting the metering rate, nozzle size and pressure levels, in order to achieve the maximum level of performance. With so many parameters involved, the blast technicians experience can play a huge role in the efficiency of an abrasive.

A section of sandstone discoloured with pollution staining was also blasted during the trial. This was not a detailed study, but rather it was used to test the feasibility of using glass grit in this application. The grit performed very well, cleaning the stone to a very high standard, without unduly eroding the surface, which is a primary concern in many projects.

Overall the glass grit, generated slightly more dust than either of the other two abrasives, however, this can be controlled, by varying blast pressures, metering rates etc. Although more dust was generated by the glass grit, the technician did not consider this to be a problem, and especially so if blasting outdoors.

The work completed to date has shown that not only can glass grit perform extremely well and is cost effective, but also that there is significant scope in the UK market for a new exciting and environmentally friendly shot-blast abrasive. Case studies documented in the UK by Enviros, are contained in the 'Recycled Glass for Shot-blasting' fact sheet, which is also available from the Remade Scotland website.

Appendix 1: Theory

It has been suggested that due to its physical and chemical properties, glass is an excellent material to be used as an expendable shot-blast abrasive.

Due to glass having a low specific gravity (a measure of its density), it means that not only do you get a greater volume of material per given weight, but it can also be an important factor when considering the energy imparted onto a surface during blasting.

As with all abrasive cleaning, the idea is to transfer kinetic (movement) energy from the particle stream to the impurity on the surface, which needs removed/prepared, with the most efficient method. Efficiency is determined by how much energy is transferred from the abrasive to the surface.

Energy can be lost through frictional effects such as air resistance, heat and noise. However, these are minimal and only reduce the overall efficiency slightly. The main loss of efficiency occurs when the particles break-up upon impact, scattering pieces and therefore dispersing the energy.

The relationship between kinetic energy (Ek), mass (m) and velocity (v) is:

$$Ek = \frac{1}{2}mv^2$$

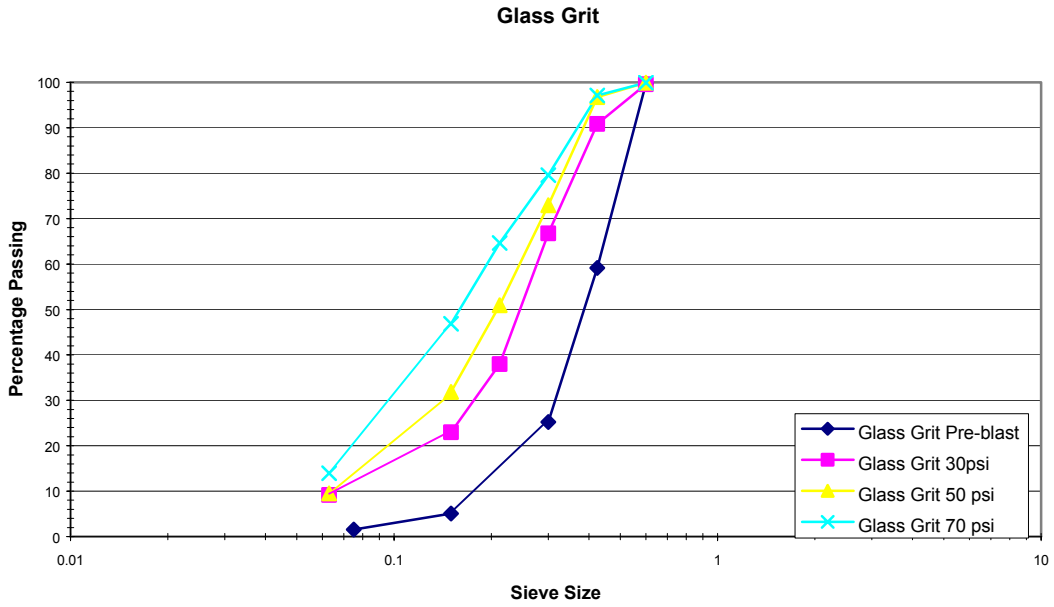
It can be seen that while there is a reduction in specific gravity (and hence a reduction in mass), which leads to a reduction in kinetic energy, the resulting increase in velocity would have a greater effect since the energy varies with the square of the velocity. Therefore, if there is a reduction in mass, but also an increase in velocity, the overall effect is an increase in energy.

It is believed that it is this effect, and the fact that the glass grains are angular to sub-angular, is why glass is proving to be a very efficient shot-blast abrasive when compared to more conventional abrasives such as copper slag and other expendable heavy abrasives.

Appendix 2: Particle size distribution analysis – glass grit

By performing a Particle Size Distribution before and after blasting, the breakdown rate of the material can be calculated.

Figure 6. Glass Grit PSD



It can be seen from the above graph, that the higher the pressure, the greater the breakdown rate is for the glass grit which is as expected, with a higher percentage of particles passing the same sieve size.

The graph shows that the glass grit has a pronounced initial breakdown, and also that the difference in pressure has a marked effect on the breakdown rate of the material.

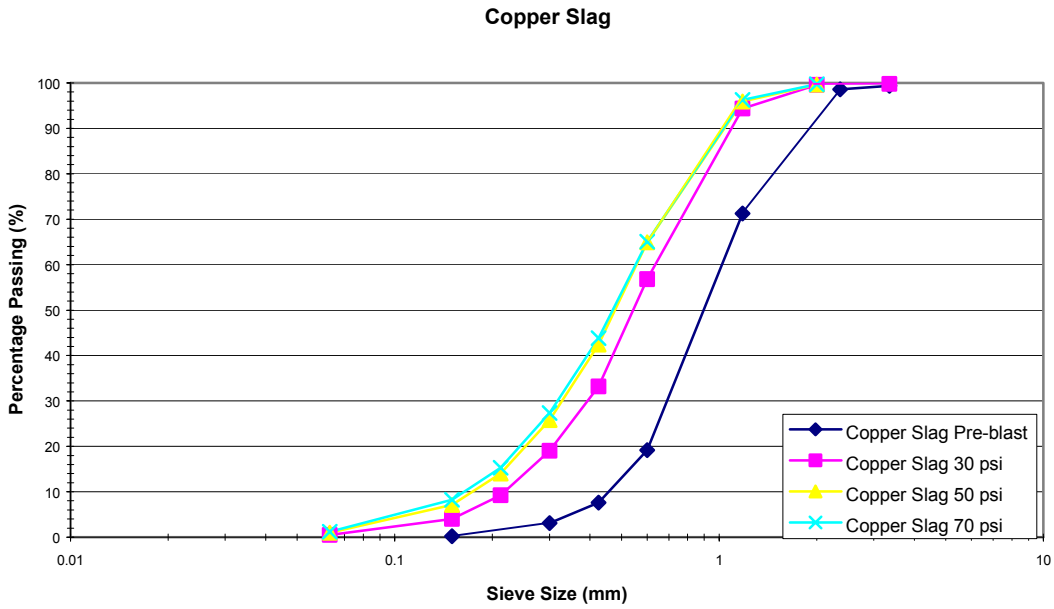
When blasting, the pressure should be adjusted until the optimum efficiency is reached, after this the surplus energy is lost in the breakdown of the abrasive rather than further cleaning/preparing the surface. This is the case for all abrasives.

A large percentage of fines were produced from the glass grit. Also, a minimal percentage of airborne dust was generated, however this is deemed to be of a clean nature when compared to dirty residue left by the copper slag.

It was estimated that glass grit could yield 2 to 3 cycles before becoming spent depending in this application.

Appendix 3: Particle size distribution analysis - copper slag

Figure 7: Copper Slag PSD



The above graph shows that the initial breakdown is high, and that the change in pressure thereafter only has a marginal effect on the breakdown of the abrasive. The graph shows only a small percentage of fines, however this was of a dirty nature and had the appearance of a dark chalk-like residue.

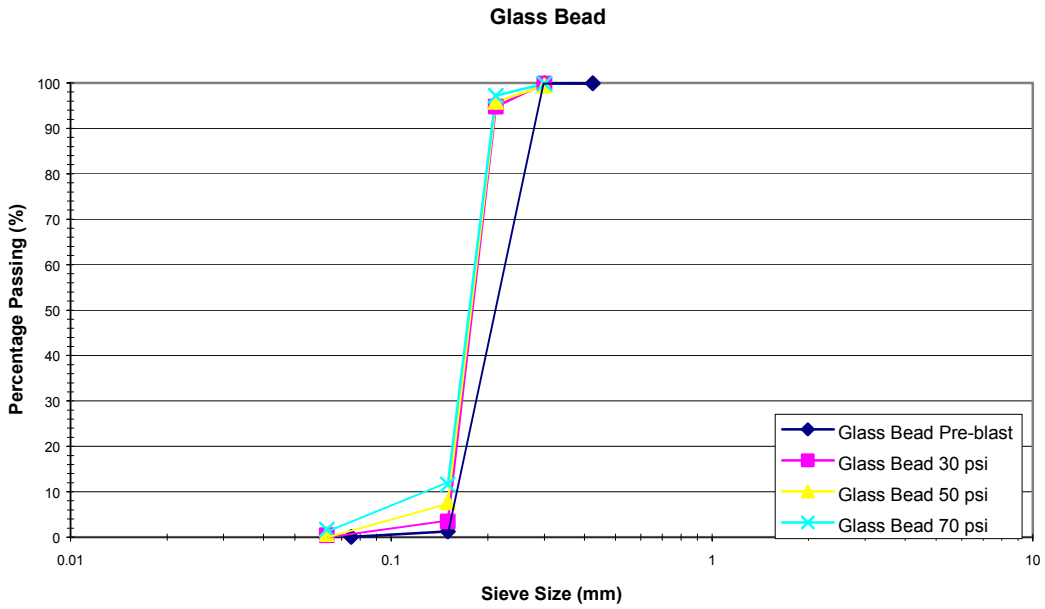
The copper slag had only a slightly less pronounced breakdown rate than the glass grit and as such only had the potential to yield one or two cycles more before becoming spent. However the copper slag is deemed an expendable abrasive, and as such would normally only be used once.

Copper slag is a by-product of copper manufacturing. During the smelting and quenching process, the mineral slag is converted to iron silicate, and it is from this that the copper slag abrasive is manufactured.

All copper slag is imported to the UK, and therefore incurs a substantial transportation cost, whilst at the same time having a detrimental effect on the environment.

Appendix 4: Particle size distribution analysis - glass bead

Figure 8: Glass Bead PSD



As expected for the glass bead, it appears to have less initial breakdown than either the copper slag or glass grit, and that there is only a marginal increase in breakdown rate with increase in pressure.

It can also be seen that as the pressure increases, there is an increase in fine particles, which correlates to the percentage of glass beads which are broken down by the increase in blasting pressure.

The results also show that the glass beads are manufactured to a very tight specification, which is demonstrated by the narrow PSD band.

Appendix 5: Time & abrasive required to clean surface

The table below shows the results of the trials performed on the mild steel plates, detailing the time taken to clean the surface and the mass of the spent abrasive.

Table 3: Blasting times & abrasive required

Abrasive/Pressure	Area (ft^2)	Time (sec)	Abrasive Mass (Kg)
Glass Grit 30psi	1	50	0.217
Glass Grit 50psi	1	35	0.231
Glass Grit 70psi	1	32	0.141
Glass Bead 30psi	1	35	0.964
Glass Bead 50psi	1	28	0.862
Glass Bead 70psi	1	21	0.415
Copper Slag 30psi	1	105	1.7
Copper Slag 50psi	1	86	0.593
Copper Slag 70psi	1	67	0.505

It can be seen from the above table, that the glass bead managed to clean the surface in the quickest time closely followed by the glass grit, with the copper slag taking the longest.

The glass grit took the least amount of abrasive to clean the surface area than either of the other two abrasives, which is not only a significant cost saving to the contractor when purchasing the abrasive, but also when taking into account the clean-up costs.

Over the three pressures the average performance of glass bead and copper slag compared to glass grit was:

Table 4: Comparison of glass bead and copper slag performance with glass grit

	Time	Abrasive
Glass Bead	-28% (approx ¾ of the time)	x 3.7 more
Copper Slag	+143% (approx 2 ½ longer)	x 4.7 more

Appendix 6: Surface analysis

The surface analysis of the finished surface is deemed to be one of the most important indicators of an abrasive's performance, and is also an important factor when determining which abrasive is suitable for which application.

There are two main aspects of surface analysis: surface cleanliness and surface profile (roughness). Surface cleanliness is usually determined by the standards set by the Swedish Institute of Corrosion, and the level of cleanliness is denoted by the letters 'Sa' ranging from 1 to 3, with 3 being the cleanest.

Surface profile is determined by the ISO Committee, where it is acknowledged that the most practical method of measuring roughness is simply to use a comparator plate, conforming to ISO 8503: Part 1, which is a plate with varying surface profiles used for a visual comparison.

A surface which has been blast cleaned will not be smooth and flat, but rather it will be uneven with sharp peaks and troughs. It is this un-evenness, which provides a good anchorage for industrial paint applications.

However, the size of the peaks and troughs are a significant factor when considering the quantity of paint required for a given surface. The rougher the surface, the more paint will be required to fill/cover the peaks and troughs, therefore great care should be taken when specifying which surface profile is most suited for each particular application.

Following blasting, the steel plates were immediately sent to Ervin Amasteel in Tipton, where they used a Taylor Hobson Surtronic 3P stylus instrument for surface profile analysis. The results were as follows:

Table 5. Surface profile & cleanliness

Plate	Ra	Ry	Rz	Assessment
Glass Grit 30psi	4.7	31.7	24.6	Sa3
Glass Grit 50psi	4.2	25.5	21.0	Sa3
Glass Grit 70psi	4.9	37.8	28.9	Sa3
Glass Bead 30psi	1.5	16.4	10.4	Sa3
Glass Bead 50psi	3.3	21.5	16.6	Sa3
Glass Bead 70psi	4.4	41.5	23.5	Sa3
Copper Slag 30psi	8.9	56.6	45.0	Sa2.5
Copper Slag 50psi	8.7	53.7	43.1	Sa2.5
Copper Slag 70psi	9.1	62.2	47.2	Sa2/2.5

Ra – average height difference between the five highest peaks and the five lowest troughs

Ry – maximum peak to trough height of the profile tested

Rz – mean of all the 'R' values obtained within the assessment length

It can be seen from table 5, that the glass grit has performed very well, cleaning the surface to a very high standard (Sa3), whilst producing a fine to medium surface profile.

Glass bead also cleaned the surface to a very high standard, however the surface profile produced had a very fine finish as expected, which is suitable for peening or polishing applications.

The copper slag did not clean to as high a standard as the glass bead or grit, however it did manage to clean to a sufficient standard, producing a medium surface profile.

It is generally acknowledged in the industry that a surface should be cleaned to a level Sa2.5 or better for most industrial paint applications. The copper slag marginally managed to achieve this although it did not perform as well as the other two abrasives.

The copper slag produced the highest surface profile, however as stated earlier in the report, this level of surface profile may not prove to be the most efficient in terms of paint required per job, with savings possibly being made where a slightly smoother surface profile may be sufficient.

Sandstone Testing

During the initial trials it was suggested that glass grit would be an excellent shot-blast medium for the removal of pollution / graffiti from various buildings and structures.

During the trial, sections of sandstone blocks with pollution staining were blasted. This was not a scientific study, but rather it was used to test the feasibility of using glass grit for this application, again compared to the copper slag and glass bead.

Figure 9. Sandstone cleaned by Glass Grit

Similar surface areas were blasted under a pressure of 30psi. The results showed that the glass grit again out performed the copper slag both in terms of surface cleanliness and time taken. It was noted that the glass grit did not unduly erode the surface of the stone (Fig. 9), which is a major factor in this application.

Glass bead also worked well on this application, but due to cost was not considered a viable option, and therefore is not considered a target market for the bead.

Appendix 7: Cost benefit analysis

As with any new product entering a market, it often isn't enough simply to compete on a performance basis alone, but more often than not it will come down to which product is going to be the most cost effective.

Following the laboratory trials, the cost effectiveness of the abrasive was investigated. The following prices of abrasive were used, although these will vary from supplier to supplier, and in particular the quantity purchased:

Glass Grit: £130 / T

Copper Slag: £85 / T

Glass Bead: £600 / T

The figures below show the cost of each medium, and do not take into account factors such as the amount of energy used, or the cost per hour for the shot-blast technician etc as these are independent of abrasive type. The results obtained were as follows:

Table 6: Cost of abrasive

Pressure (psi)	**Glass Grit (£/m^2)**	**Glass Bead (£/m^2)**	**Copper Slag (£/m^2)**
30	0.31	6.43	1.61
50	0.33	5.75	0.56
70	0.20	2.77	0.48
Ave	0.28	4.98	0.88

The above table shows that as the pressure increases, the cost per area cleaned decreases. This will continue until the optimum efficiency is reached, where it will start to become inefficient due to the energy from the increase in pressure being lost in the breakdown of the material, rather than it being imparted onto the surface area to be cleaned.

The table shows that glass grit worked out to be by far the most economical medium during the trial, which was largely helped by the fact very little medium was required to clean the given area.

The glass bead worked out to be by far the least economical medium to use, largely due to it costing up to approximately six times that of the other abrasives, however the bead would normally be used in more specialist applications where a fine surface finish is required. It must be noted that since the trial, the cost of glass grit has decreased and is now more in line with the price of Copper Slag.

Appendix 8: Industry standards

Over the years a number of standards have been in use, such as:

BS 4243: 1967 UK

S.I.S. 05-59-00 Sweden

SSPC-SP-52T USA

DIN 18364 Germany

Table 7: Industry standards

BS 4232	SSPC	SIS	DIN 18364	% to be Clean	Allowable Residues
1st Quality	White Metal SP5	Sa 3	Level 3	Total	Nil
2nd Quality	Near White Metal SP10	Sa 2.5	Level 2	95	< 10%
3rd Quality	Commercial SP6	Sa 2	Level 1	80	< 40%

These standards have now been superseded by: ISO 8501 – 1: 1988 (E). The UK version of ISO 8501 – 1 is included in BS 7079. This differs from the ISO standard in that it has additional pages showing the appearance of surfaces blasted with different abrasives.

ISO 8501 Visual Assessment of Surface Cleanliness

Four grades of contamination are established and are as follows:

Rust Grade A – Intact mill scale, little or no rust.

Rust Grade B – Mill scale flaking, surface beginning to rust.

Rust Grade C – Mill scale rusted away or may be scraped off, slight pitting under normal vision.

Rust Grade D – Mill scale rusted away, general pitting under normal vision.

Table 8: ISO 8503 Comparator plate grades of roughness

Grade	Profile (microns)
Fine	23 – 28
Medium	50 – 70
Coarse	85 – 115
Coarser Than Coarse	130 - 170

Appendix 9: Shot blast abrasive suppliers/manufacturers

Supplier/Manufacturer	Contact Details
Airblast Ltd	King Street Industrial Estate, Langtoft Peterborough, PE6 9NF Tel: 0345 697 225
Carborundum Abrasives	3 Sandpiper Way, Strathclyde Business Park Bellshill, ML4 3NG Tel: 01698 741 070
Carlton Abrasives	212 Redpath Drive Glasgow, G52 2ER Tel: 0141 883 9172
Correcoat Ltd[2]	Forster Street, Leeds West Yorkshire, LS10 1PW Tel: 0113 276 0760
Ervin Amasteel	George Henry Road, Great Bridge Tipton, West Midlands, DY4 7BZ Tel: 0121 522 2777
GMA Garnet	PO Box 9, Middlewich Cheshire, CW10 9FD Tel: 01606 836 233
Merit Abrasives Ltd	467 – 471 Hillington Road Glasgow, G52 4PP Tel: 0141 883 4777
Metabrasive Ltd	Capponfield Works, Coseley Road Bilston, West Midlands, WV14 0RJ Tel: 01902 402 131
Potters Europe	Pontefract Road, Barnsley South Yorkshire, S71 1HJ Tel: 01226 704 515
Scangrit	Eastfield Road, South Killingholme Grimsby, N. East Lincolnshire, DN40 3NF Tel: 01469 574 715
Shotblast Supplies Ltd	10 – 20 Kilton Terrace, Worksop Nottinghamshire, S80 2DQ Tel: 01909 530 107
Tyne Grit Supplies Ltd	Collingwood House, Lawson Street North Shields, Tyne & Wear, NE29 6TG Tel: 0191 415 3030
USF Vacu-Blast International	Woodson House, Ajax Avenue Slough, Berkshire, SL1 4DJ Tel: 01753 526 511
Washington Mills Electro Minerals Ltd	Mosley Road, Trafford Park Manchester, M17 1NR Tel: 0161 848 0276
Wolverhampton Abrasives Ltd[2]	Orgreave Drive, Handsworth Sheffield, S13 9NR Tel: 0114 254 0742

[2] Sell Recycled Glass Grit Abrasive

Appendix 10: Shot blast Contractors

Shot blast Contractor	Contact Details
A & M Stone Cleaning	78 Onthank Drive Kilmarnock, KA3 2BX Tel: 01563 537 675
Aberdeen Blast Cleaning Services Ltd	Hillview Rd Aberdeen Aberdeenshire AB12 3HB Tel: 01224 896565
Aliblast Services	Greenpark Service Station Edinburgh Rd Linlithgow West Lothian EH49 6AA Tel: 01506 671844
Arlington Blast	Garvies Industrial Estate, Highland Road Milngavie, G62 Tel: 0141 956 2351
Ashley Industries Ltd	Raiths House Kirkton Drive Dyce Aberdeen Aberdeenshire AB21 0BG Tel: 01224 722299
Autoblast Services	Lower Larchfield Works Walton Street Dundee, DD1 5BL Tel: 01382 223 255
B.A.C.C	M90 Commerce Park Lathalmond Dunfermline Fife KY12 0SJ Tel: 01383 626301
B.B.C Blast Cleaning	Springfield Industrial Estate Ballieston 0141 781 4900
Bead Blasting Services	Lochavullin Rd, Oban Argyll, PA34 4PL Tel: 01680 814 219
Blast Off Ltd	Shanks Industrial Park Victoria Rd Barrhead Glasgow Lanarkshire G78 1NQ Tel: 0141 881 4142
Branac (Irvine) Ltd	2-4, Whittle Place South Newmoor Ind Est Irvine Ayrshire KA11 4HR Tel: 01294 211988
Broxburn Shotblasting Protective Coatings Ltd	Unit 7, Albyn Ind Est Greendykes Rd Broxburn West Lothian EH52 6PQ Tel: 01506 852988
Cairnhill Blast Cleaning	7, Imperial Drive Airdrie Lanarkshire ML6 9EL Tel: 01236 766980
Cam-Rex Coatings Services	Unit 9 Headswood Denny Stirlingshire FK6 6BW Tel: 01324 829454
Central Blasting & Painting Ltd	Carron Works, Stenhouse Rd Carron Falkirk, Stirlingshire FK2 8DR Tel: 01324 611001

D.S Cleaning Services	84, Crawford Rd Houston Johnstone Renfrewshire PA6 7DA Tel: 01505 327455
Denholm Industrial Services Ltd	Greenbank Place, East Tullos Industrial Estate Aberdeen, Aberdeenshire, AB12 3BT Tel: 01224 248 600
Flirok UK Ltd	97, Hazelden Gardens Giffnock Glasgow Lanarkshire G44 3HQ Tel: 0141 633 1647
Findhorn Grit Blasting	Cullerne Farm Findhorn Forres Morayshire IV36 3RY Tel: 01309 690285
Finesse Quality Coatings Ltd	27, Cotton St Aberdeen Aberdeenshire AB11 5EE Tel: 01224 581725
Forblast Ltd	33 Balvenie Street Keith, AB55 4AS Tel: 01340 820 241
G.C.G Shotblasting Services Ltd	Unit 3, Dales Ind Est Peterhead Aberdeenshire AB42 3JF Tel: 01779 475002
G.D Crichton	Strathendry Mill Leslie Glenrothes Fife KY6 3HU Tel: 01592 743181
G.M.S MOT Station	2a, Elphinstone Rd Tranent East Lothian EH33 2HR Tel: 01875 614411
Gemini Corrosion Services Ltd	Broomhill Rd Spurryhillock Ind Est Stonehaven Kincardineshire AB39 2NH Tel: 01569 765488
Gilcomston Construction Ltd	Unit 1, The Quay,Main St Newburgh Ellon Aberdeenshire AB41 6AA Tel: 01358 789563
Henderson's Metal Cleaning	1-3, Piershill Lane Edinburgh Midlothian EH8 7EJ Tel: 0131 661 0870
Industrial Blasting Services	Unit 18b,Olympic Business Park Drybridge Rd Dundonald Kilmarnock Ayrshire KA2 9BE Tel: 01563 851070
J.B. Blasting	2 Atholl Gardens Kilwinning Tel: 01294 558 261
J.D. Grit Blasting	Unit 2, Canderside Industrial Estate Birkenshaw, ML9 Tel: 01698 307 226
J.T. Commercial Blasting	Bridgeness Rd Bo'Ness West Lothian EH51 9JR Tel: 01506 829463
Kingsway Shotblasting Services	Loons Rd Dundee Angus DD3 6AQ Tel: 01382 566769
Lanarkshire Blast Cleaning Co.Ltd	37, Birkenshaw St Glasgow Lanarkshire G31 2UH, Tel: 0141 556 1162

M.B.C. Blast Cleaning Services	Mosstocloch Industrial Estate Fochabers, IV32 7LH Tel: 01343 820 923
M M S	Lower Bathville Business Park Armadale Bathgate West Lothian EH48 2ND Tel: 01501 732038
Mitie Hydrocat	Unit A, Howe Moss Drive Kirkhill Ind Est Dyce Aberdeen Aberdeenshire AB21 0GL Tel: 01224 724455
Moray Blast Cleaning Services	Mosstodloch Ind Est Garmouth Rd Mosstodloch Fochabers Morayshire IV32 7LH Tel: 01343 820923
Moulds	52, Sandbed St Kilmarnock Ayrshire KA1 1QA Tel: 01563 544973
Normar Ltd	Unit G2 Mitsui Babcock Business Park Renfrew Renfrewshire PA4 8JD Tel: 0141 885 3600
Palmers Ltd	Grangemouth Rd Bo'Ness West Lothian EH51 0PU Tel: 01506 822211
Peter (Patsy) Bruce	Slipway, Reclaimed Ground South Harbour Rd Fraserburgh Aberdeenshire AB43 9TA Tel: 01346 514056
Pharo Blasting	Unit 2, Canderside Industrial Estate Larkhall, ML9 2TP Tel: 01698 307 226
Possilpark Shotblasting Co.Ltd	73, Dunn St Glasgow Lanarkshire G40 3PE Tel: 0141 556 6221
Precision Powder Coating	101 Abercorn Street Paisley, PA3 4AY Tel: 0141 848 7477
Premier Surface Blasting	Newbattle Abbey College Annex Newbattle Road Dalkeith, EH22 3LJ Tel: 0131 663 2344
Rigblast Energy Services Ltd	North Nolfolk House, Pitmedden Rd Dyce Aberdeen Aberdeenshire AB21 0DP Tel: 01224 722888
Ross & Bonnyman Painting & Shotblasting	Unit 5, Orchardbank Ind Est Forfar Angus DD8 1TD Tel: 01307 466889
S & G Specialist Coatings	2, Rose St Burntisland Fife KY3 0EG Tel: 01592 871360
S & M Shotblasting Ltd	Carronview, Glensburgh Grangemouth, FK3 8XL Tel: 01324 666 515
S.M.S Shotblasting Ltd	Edinburgh Dock, East Leith Docks Edinburgh Midlothian EH6 7DW Tel: 0131 554 8325
S. Warnock & Son	8 Main Road Gatehead, Kilmarnock Tel: 01563 536 265

Salamis Ltd	4 Greenhole Place, Bridge of Don Aberdeen, Aberdeenshire, AB23 8EU Tel: 01224 246 000
Scotblast	West Benhar Rd Harthill Shotts Lanarkshire ML7 5PG Tel: 01501 753244
Scottish Galvanizers Ltd	MacLellan Street Glasgow, G41 1RR 0141 427 3041
Serinco Metal Finishers Ltd	73, Whitecraigs Rd Glenrothes Fife KY6 2RX Tel: 01592 773755
Shotblast Products	17 Evanton Place Thornliebank, Glasgow Tel: 0141 620 1652
Stirling Shotblasting Services	Unit 64, Bandeath Industrial Estate Stirling, FK7 7EW Tel: 01786 448 188
Sureclean Ltd	10, River Drive,Teaninich Ind Est Alness Ross-Shire IV17 0PG Tel: 01349 884480
Tayblast Services Ltd	Corrosion Centre, Lunan Bay Montrose Angus DD10 9TG Tel: 01241 830513
Thomas Martin	2 Brow Cottages Annan Dumfriesshire DG12 6 Tel: 01461 700050
Tytan Jetting Ltd	Unit 4, Castle St Castlepark Ind Est Ellon Aberdeenshire AB41 9RF Tel: 01358 729444
Warnock & Son	1 Busbie Cottage, Crosshouse Rd Knockentiber Kilmarnock Ayrshire KA2 0BY Tel: 01563 536265
Waterblasters	31 Trinity Crescent Edinburgh Midlothian EH5 3EE Tel: 0131 551 1237
Wilkie-Hooke Ltd	Grangemouth Road Bo'ness, West Lothian, EH51 0QB Tel: 01506 822 211