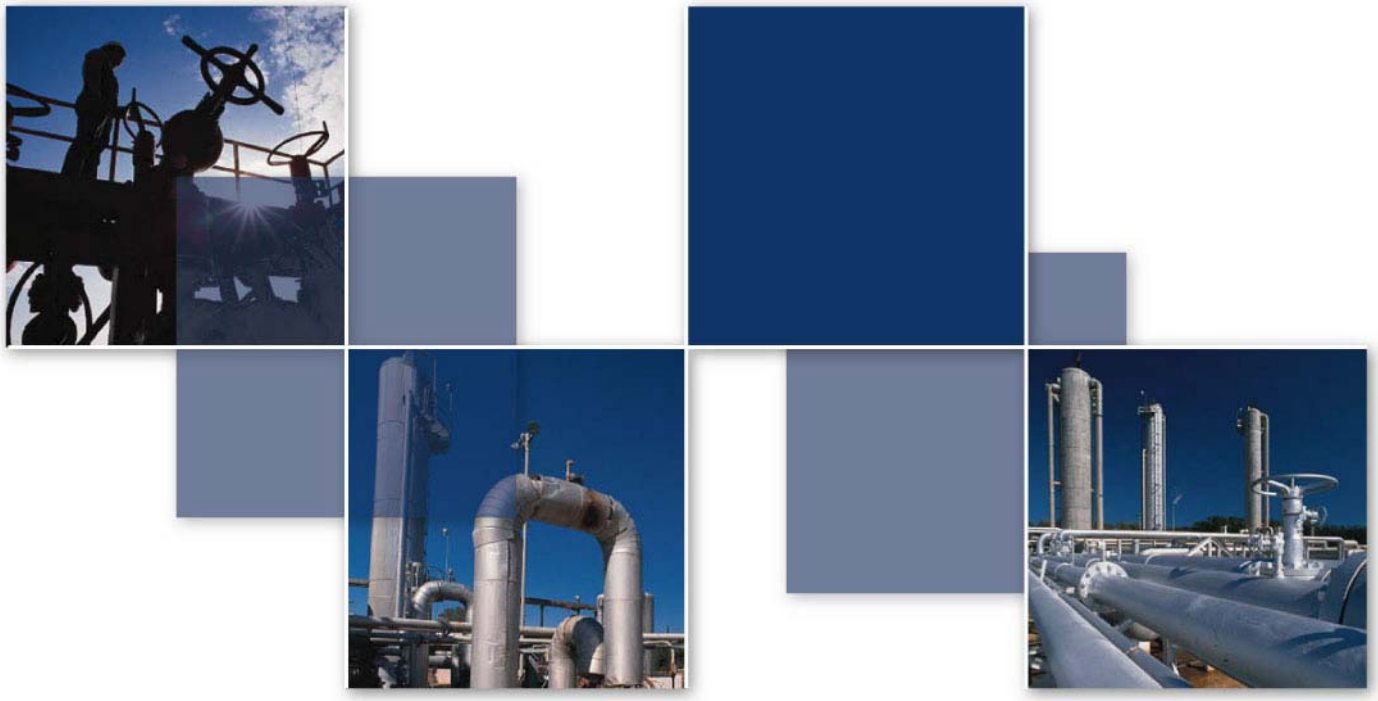

Investigation into the suitability of commercially available recycled glass as a blast medium

For the attention of:
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1 INTRODUCTION

CAPCIS Ltd was instructed by the Marine Painting Forum to investigate the suitability of commercially available recycled glass as a blast medium.

The Marine Forum has been considering the use of recycled glass as an abrasive medium, but was concerned about transfer of possible contamination within the recycled glass to the steel surface to be coated. This contamination might influence the blast surface cleanliness, with consequent reduction in the quality of the prepared surface and performance of coatings applied to it.

CAPCIS Ltd understood that the Forum wished to investigate the potential of transfer of contamination from the recycled glass onto the blasted surface using Scanning Electron Microscopy (SEM) and Environmental Scanning Electron Microscopy (ESEM). The Forum is aware that the quality of recycled glass abrasive medium can depend upon the provider and it is understood that the supplier of recycled glass is not obliged to clean the collected glass. Contamination therefore might include ingredients from food sources (e.g. cooking oils) or other contaminants associated with glass recycling.

2 TEST PROGRAMME

The Marine Painting Forum decided to compare steel surfaces prepared using two blast media, aluminium oxide (with a solvent wash) and chilled iron grit, with commercially available recycled glass.

2.1 TEST SPECIMENS

It was decided to use mild steel sheet which was cut into small coupons (1cm x 1cm x 3mm thick) prior to blasting. The coupons were then fixed into the newly developed Morris "Blastagrip" (a frame to hold the coupons in place) and the exposed surfaces blasted with the various abrasive media. All specimens were prepared at Leigh's Paints in Bolton and given to CAPCIS for further analysis. CAPCIS received 4 coupons prepared with each of the specified blast media and 8 coupons of base material for analysis, Table 1.

Table 1: Analysis matrix

Coupon type	Analysis technique			
	Visual	SEM	ESEM	ESEM wet
As received	X			
As received and degreased	X	X	X	X
Chilled iron grit	X	X	X	
Aluminium oxide with solvent wash	X		X	
Recycled Glass	X		X	X

2.2 ANALYSIS TECHNIQUES

Visual examination involved assessment of the surface by naked eye, stereo microscope and assessment of the surface profile.

SEM examination involved the assessment and analysis of the coupons under high vacuum. An SEM is a microscope capable of producing high-resolution images of a sample surface.

ESEM examination involved the assessment and analysis of the coupons under low vacuum which allows the examination of wet, oily, dirty, out-gassing and non-conductive samples in their natural state without (in many cases) sample modification or preparation.

Secondary Electron (SE) imaging is the most common imaging mode. Due to the low energy (<50 eV), these electrons originate from within a few nanometers of the surface

Back Scattered Electron (BSE) imaging can be used to detect contrast between areas with different chemical compositions especially when the average atomic number of the various regions is different.

Energy Dispersive X-ray spectroscopy (EDX) allows the elemental analysis of the surface or particles on the surface in both SEM and ESEM.

3 RESULTS

All images and analyses are attached in the appropriate Appendices.

3.1 VISUAL AND OPTICAL MICROSCOPIC OBSERVATIONS

The images are attached in Appendices A and B.

The as-received and the reference coupon showed a characteristic hot rolled surface and mill scale, A1, A2, B1, and B2.

The chilled iron grit blasted surface appeared to be rougher with an apparent large proportion of rogue peaks, A1, A3, and B3.

The aluminium oxide blasted surface appeared to be more uniform than the chilled iron grit blasted one. Of the coupons examined, the aluminium oxide blasted coupon was most lustrous, A1, A4, and B4.

The surface of the coupon blasted with recycled glass appeared non-uniform but smoother than the aluminium oxide blasted one, with a matt surface appearance, A1, A5, and B5. The edges of the blasted area were less defined, indicating areas of lower blasting efficiency, A5.

The surface roughness was estimated using a surface profile comparator (grit) and TESTEX tape, Table 2. These results confirm the above visual findings.

Table 2: Surface profile of the blasted coupons

Coupon type	**Surface profile technique**
	Comparator
Chilled iron grit	Medium profile
Aluminium oxide with solvent wash	Medium profile
Recycled Glass	Fine profile

No visual contamination was observed on any of the coupons examined.

3.2 RESULTS FROM THE SEM INVESTIGATION

All images and analyses are attached in Appendices C to D.

The general surface topography of the reference coupons was typical of a hot rolled steel surface, C1 to C4. EDX analysis of the surface, C5 and some particles, C6 and C7, showed elements (Fe, Mn, C) typical for mild steel and oxygen associated with an iron oxide film (mill scale). No contamination from the degreasing medium or handling (Cl peak indicative of sweat) was found.

The surface topography of the coupon blasted with chilled iron grit appeared rough with rogue peaks and valleys and the surface showed plastic deformation due to the blasting process, D1 to D4. EDX analysis of the overall surface, D5, shows the typical elements present in mild steel (Fe, Mn, C) and the absence of a significant oxygen peak, indicating the removal of the mill scale.

At higher magnifications, analysis of particles found on the surface indicated that they were associated with residual mill scale, D6, or contaminants within the chilled iron grit such as SiO_2, Aluminium silicate, sand etc from iron slag[1], D7 to D10. The absence of Cl indicates that the contamination was most likely not caused by handling.

3.3 RESULTS FROM THE ESEM INVESTIGATION

The images and analyses are attached in Appendices E to H.

The reference coupon showed little contamination and the majority of spectra obtained of the surface and particles were associated with iron oxide from the mill scale, E4 to E6. However, a few small particles were found to contain tin, E7 and E8.

Contamination found on the coupon blasted with iron grit was mainly associated with SiO_2, F7 to F9 and mill scale, F10 to F12. Some small particles were found to contain Na and Ca, F7 to F9. As no Cl peak was found, the presence of these elements is not thought to have been caused by handling and hence was most likely part of the iron grit blast media.

Little contamination (Sn, and Cr) was found on the coupon blasted with aluminium oxide (with solvent wash), G3 to G7, which were most likely part of the aluminium oxide blast media.

The coupons blasted with recycled glass showed the highest density of particles at the surface, H2, H4, and H11. The majority of the particulate contamination was associated with lead, H12. These lead containing particles appeared to have been deformed on impact on the surface, moulding around the surface peaks, H10. Other particles found on the surface contained Si, Na, Ca, O etc which are general constituents of glass, H6 to H8, and H13 to H15.

[1] See also BS EN ISO 11124-2:1997
Preparation of steel substrates before application of paints and related products. Specifications for metallic blast-cleaning abrasives. Part 2: Chilled-iron grit

3.3.1 Wetting characteristics

Since no oil type contamination was detected by EDX analysis, the wetting characteristics of one coupon blasted with recycled glass was investigated. An oil-contaminated surface would show a water repellent effect with beading of water droplets in comparison to an uncontaminated one.

The ESEM images, I1 to I3 in Appendix I show the wetting process and effect on the coupon blasted with recycled glass and the reference coupon. Initial wetting of the surfaces, I2, resulted in the formation of small puddles/droplets at discreet sites. For the glass blasted coupon, these initiation sites are located within the valleys of the blasted surface. Wetting the surfaces further led to an increase in puddle/droplet size which eventually joined to flood the surface. No real differences, and more importantly, no water repellent effects were observed on the glass blasted coupon.

The wetting process around a particle, which may have been a site for oil contamination has also been investigated, I4. Again, no water-repellent effects were observed and the coupon's surface appears to flood through the channels and valleys present in the surface roughness.

4 DISCUSSION

4.1 VISUAL APPEARANCE

The surface roughness and appearance is determined by a number of properties related to the abrasive material, hardness and shape, the blasting conditions, pressure, distance etc. It is understood that the general blasting conditions were the same for all coupons and independent of the material used.

Chilled iron grit is a very hard, sharp and angular material with sufficient mass to enable it to impart very coarse surface profiles with rapid removal of surface contamination.

Aluminium oxide is also a sharp and angular abrasive which enables fast removal of surface.

Both of the above abrasive media resulted in a medium profile by ISO comparator (ISO8503).

Recycled glass for abrasive purpose is produced by crushing the collected glass, hence the particles are sharp but brittle due to the nature of glass. It is assumed that the brittle nature of the glass causes the glass particles to pulverise upon impact on the surface[2], resulting in a finer surface profile in comparison to the above two media. This could have also caused the lower blasting efficiency at the edges and the general irregular appearance of the blasted surface.

4.2 CONTAMINATION

SEM and ESEM imaging and analysis showed that the chilled iron grit and the aluminium oxide (with solvent wash) blasted coupons showed some particulate contamination, but these particles were low in number.

In comparison, the glass blasted coupons were contaminated with a large number of large and small particles (bright spots in the ESEM images). These particles contained elements present in the glass itself and lead. The lead base particles were most likely carried over from the recycling process. Even though the detection of lead was initially a surprise finding, the source of the lead can be traced back to the initial bottle/glass collection. Lead is a known contaminant of recycled glass, as are aluminium, brass, and stainless steel from bottle lids and caps.

Although oil was not found, it is not safe to assume that oil is not present within a batch of recycled glass, as the level and type of contaminations seem to be dependent upon the source and the cleaning process of the recycled glass. The type of contaminants that recycled glass can contain and their contamination limits are listed in Table 3:

[2] This assumption is supported by observations made by Malcolm Morris, Leighs Paint – Telephone conversation 08/11/2006 – Malcolm Morris observed that once the glass impacted on the surface, an enormous amount of dust was produced

Table 3: Contamination limits[3]

Contaminant	Maximum permissible level upon testing [ppm]
Inorganic material	50
Organic material	500
Non-ferrous metal	20
Ferrous metal	50

A specification for best practises in glass recycling, including levels and type of contamination focussing on the end use, have been published by BSI in consultation with WRAP[3].

[3] PAS 102-2004 Specification for processed glass for selected secondary end markets
PAS 101 Recovered container glass – Specification for Quality and guidance for good practice in collection

5 CONCLUSION

On the basis of the investigation undertaken, it is concluded that:

1. More particulate contamination were found on the glass blasted surface than on other prepared surfaces examined in this investigation.
2. Glass blasting caused contamination by metals (Pb) carried over from the recycling process.
3. Glass blasting caused more extensive surface contamination by particulate matter. This may be a consequence of the brittle nature of the glass used.
4. Glass blasting was not very efficient, i.e. did not produce an even profile across the entire surface of the test coupon.

6 RECOMMENDATIONS

Before a decision regarding the suitability of recycled glass as a abrasive medium can be made, it is recommended to review the following:

- Achievable surface profile and blast efficiency – This may include blasting parameters / conditions.
- Effect of lead or other contaminants (if any) on the performance of applied coatings such as adhesion, corrosion resistance etc.
- Different sources of recycled glass including characterisation of glass (contamination levels and type) to ensure consistent results.

APPENDIX A:

GENERAL SURFACE APPEARANCE

APPENDIX B:

Surface Appearance using a stereo microscope

APPENDIX C:

SEM INVESTIGATION OF THE REFERENCE COUPON

APPENDIX D:

SEM INVESTIGATION OF COUPON BLASTED WITH CHILLED IRON GRIT

APPENDIX E:
ESEM INVESTIGATION OF THE REFERENCE COUPON

APPENDIX F:
ESEM INVESTIGATION OF COUPON BLASTED WITH CHILLED IRON GRIT

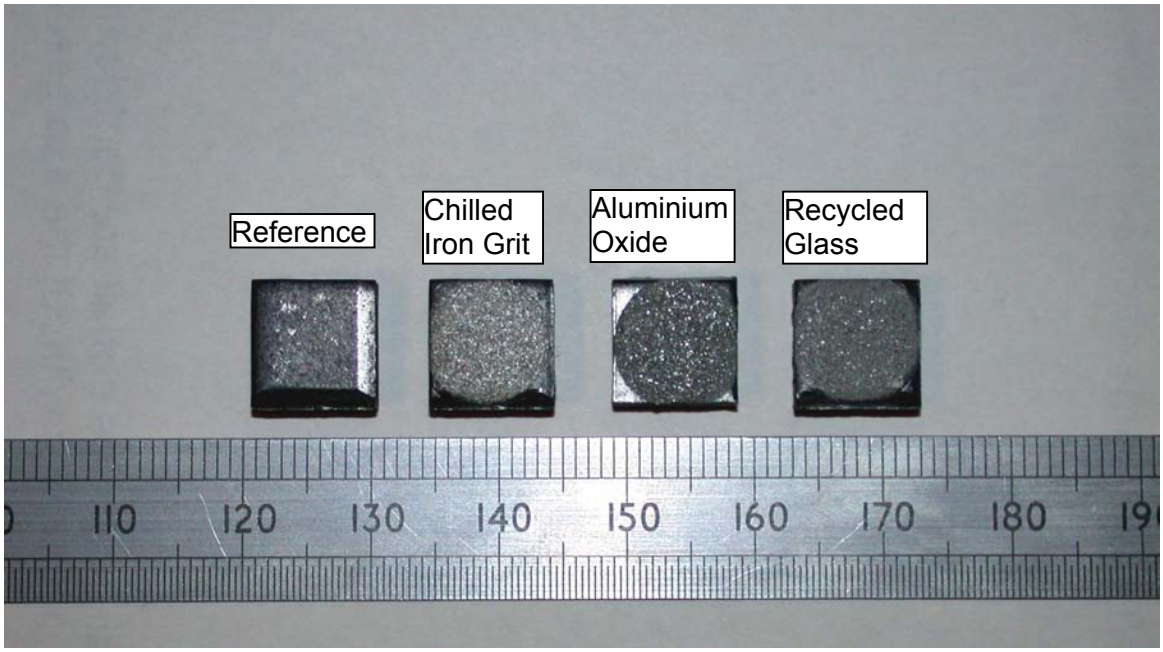
APPENDIX G:

ESEM INVESTIGATION OF COUPON BLASTED WITH ALUMINIUM OXIDE (WITH SOLVENT WASH)

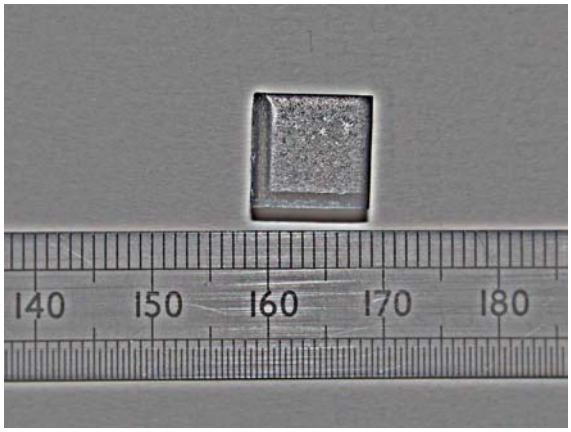
APPENDIX H:
ESEM INVESTIGATION OF COUPON BLASTED WITH RECYCLED GLASS

APPENDIX I:
INVESTIGATION OF SURFACE WETTING CHARACTERISTICS USING THE ESEM

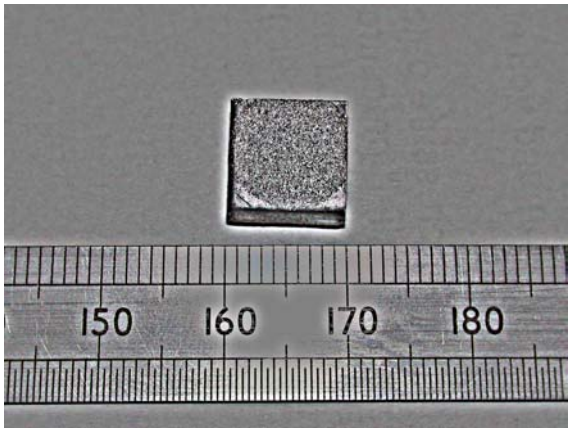
GENERAL SURFACE APPEARANCE



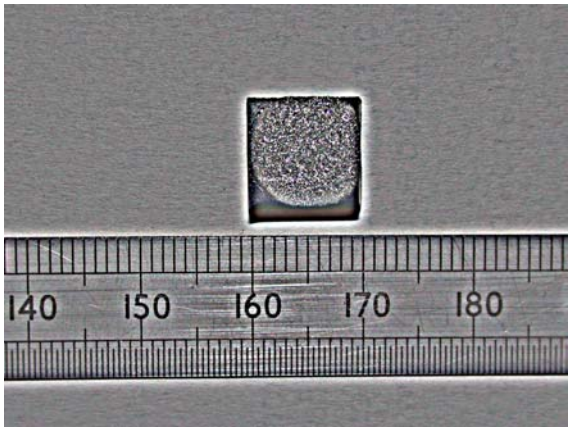
A1: General comparison of the coupons



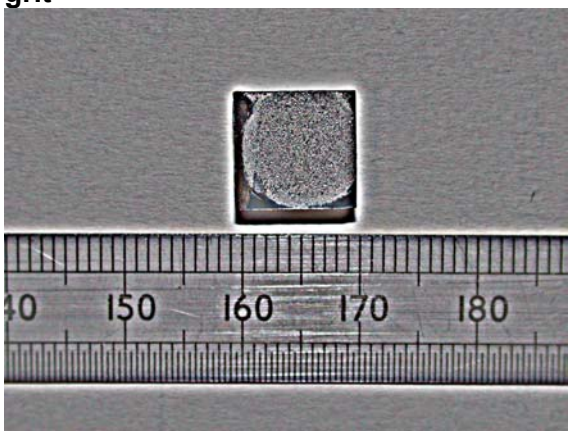
A2: Reference coupon



A3: Coupon blasted with chilled iron grit



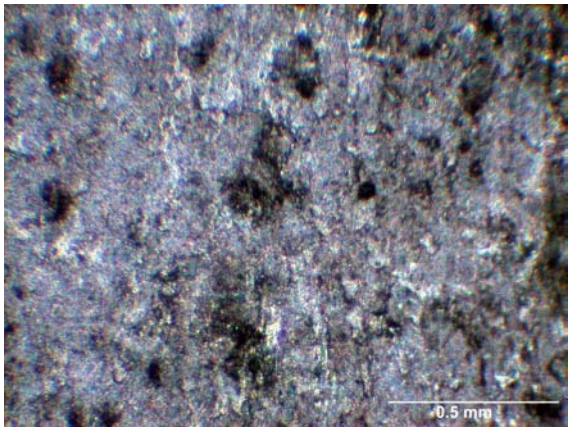
A4: Coupon blasted with aluminium oxide followed by solvent wash



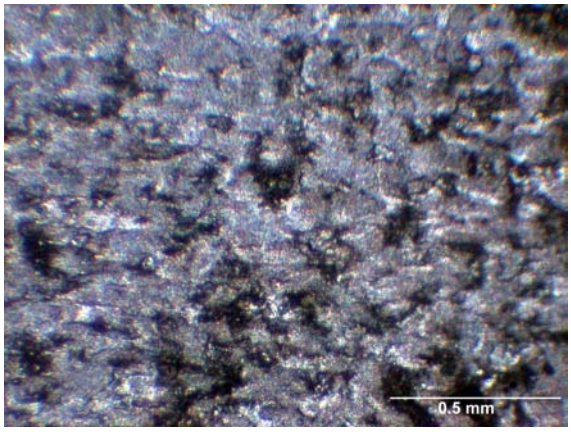
A5: Coupon blasted with recycled glass

A2 to A5 were digitally manipulated using a high pass filter to give a better contrast of the surfaces

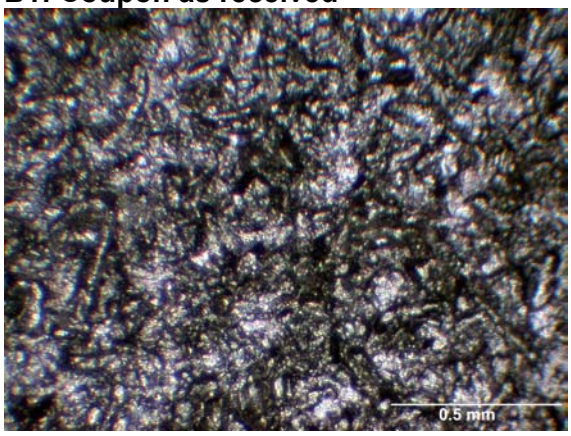
SURFACE APPAREANCE USING A STEREO MICROSPCOPE



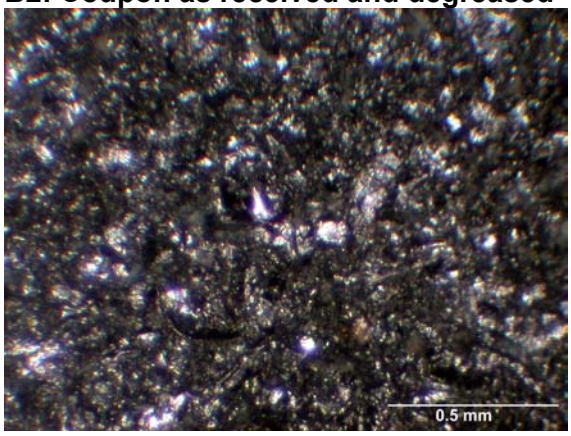
B1: Coupon as received



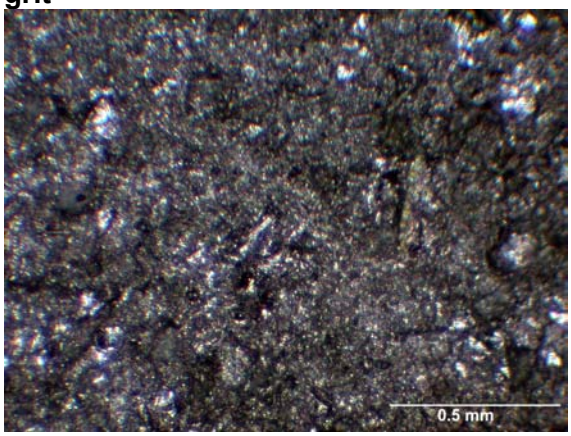
B2: Coupon as received and degreased



B3: Coupon blasted with chilled iron grit

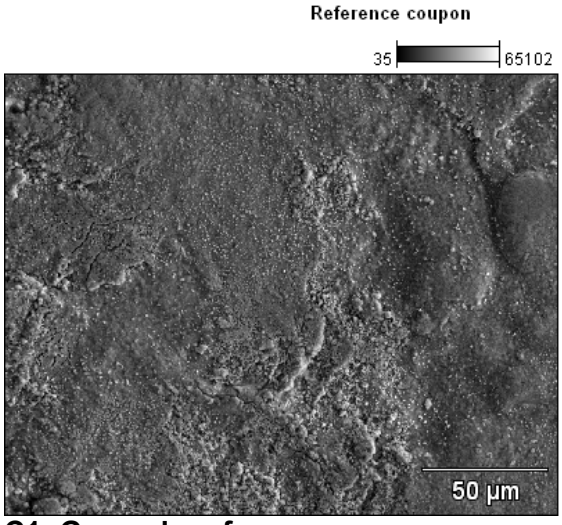


B4: Coupon blasted with aluminium oxide (with solvent wash)

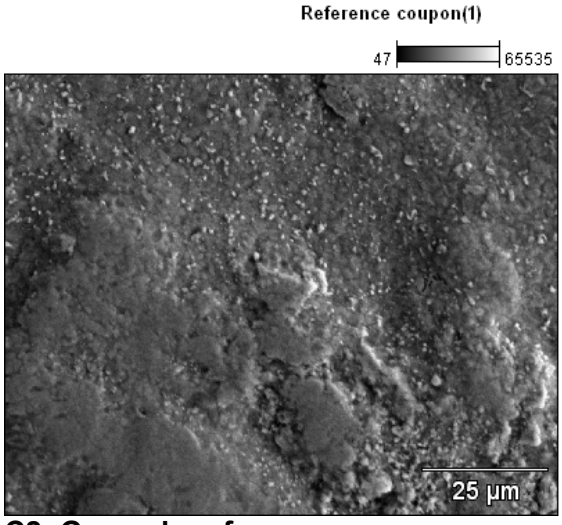


B5: Coupon blasted with recycled glass

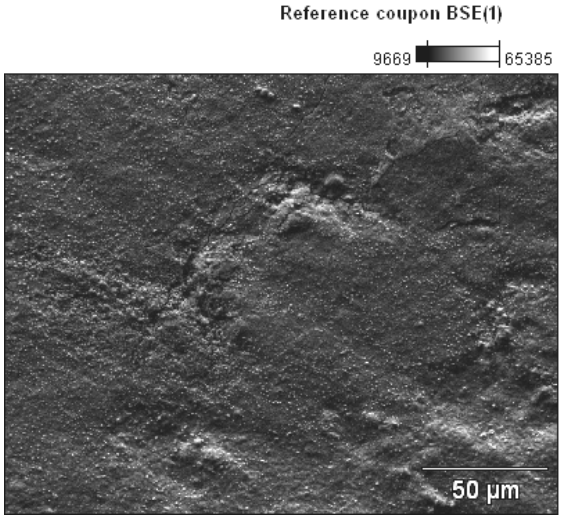
SEM INVESTIGATION OF THE REFERENCE COUPON



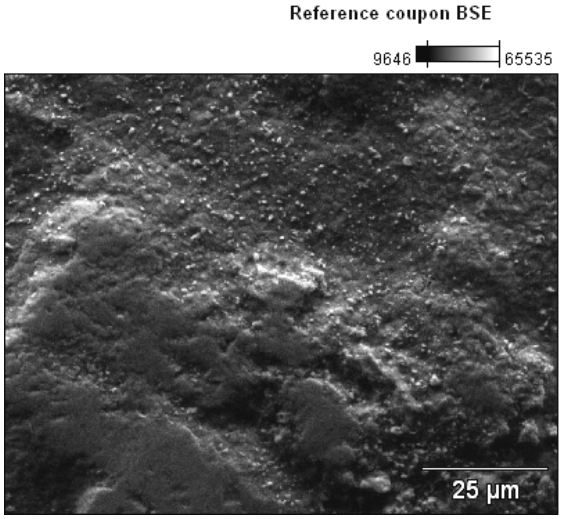
C1: General surface appareance Magnification x500



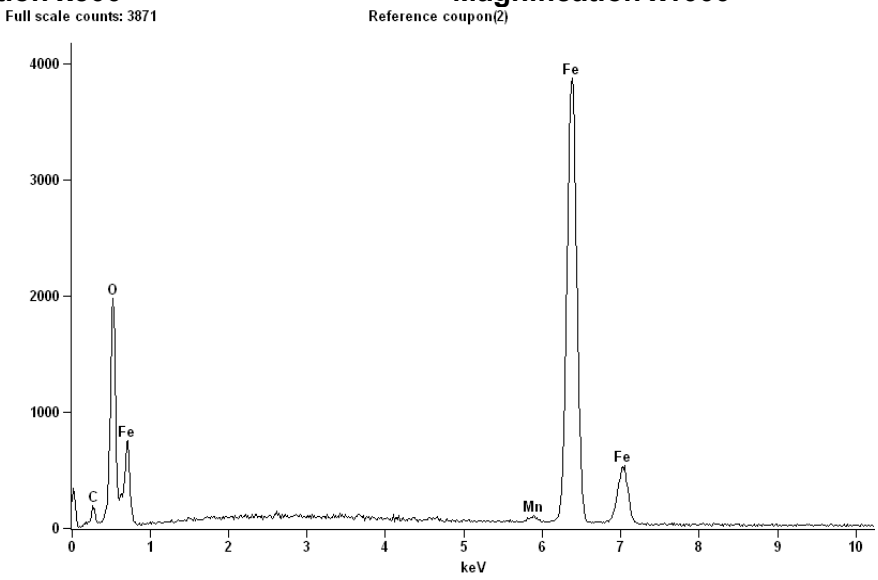
C2: General surface appareance Magnification x1000



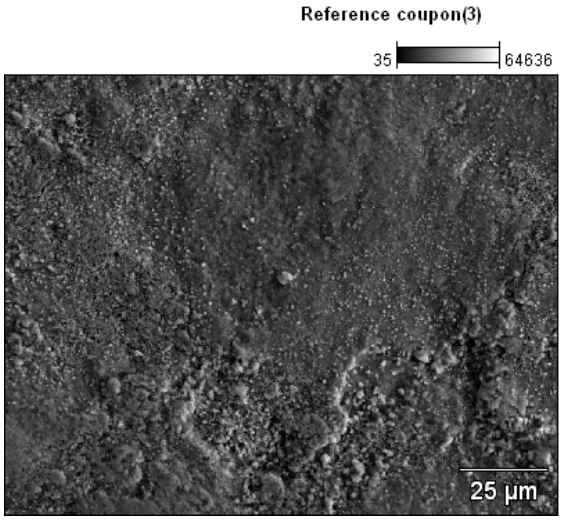
C3: General surface appareance (BSE) Magnification x500



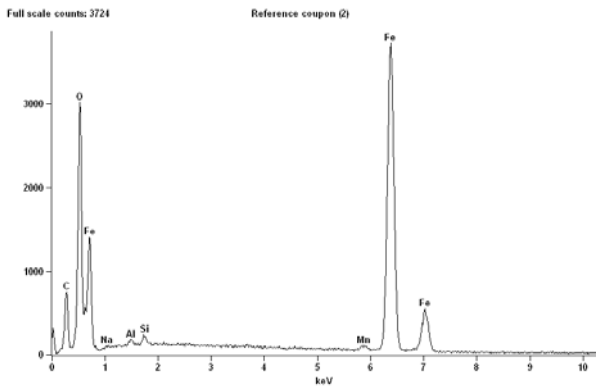
C4: General surface appareance (BSE) Magnification x1000



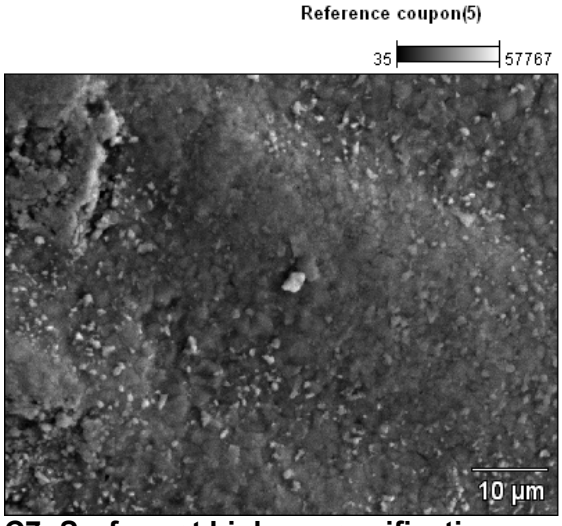
C5: EDX Spectra of general surface



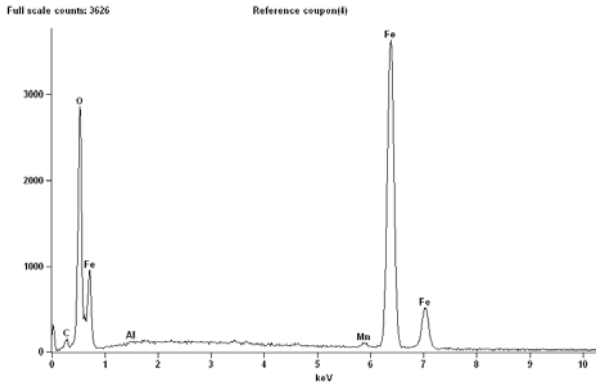
C6: Surface at higher magnification, x700



EDX Spectra of particle (left)

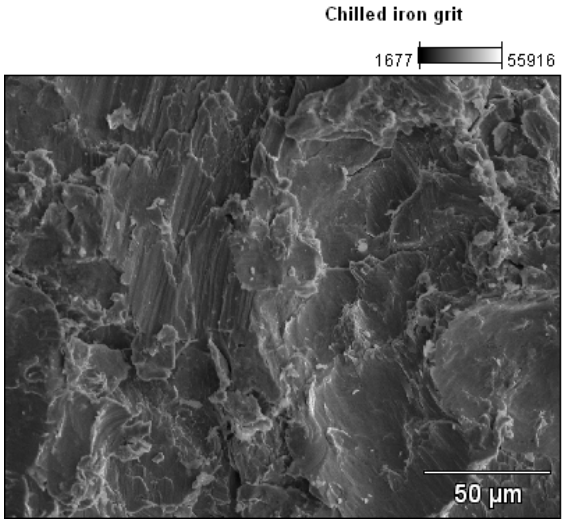


C7: Surface at higher magnification, x1500

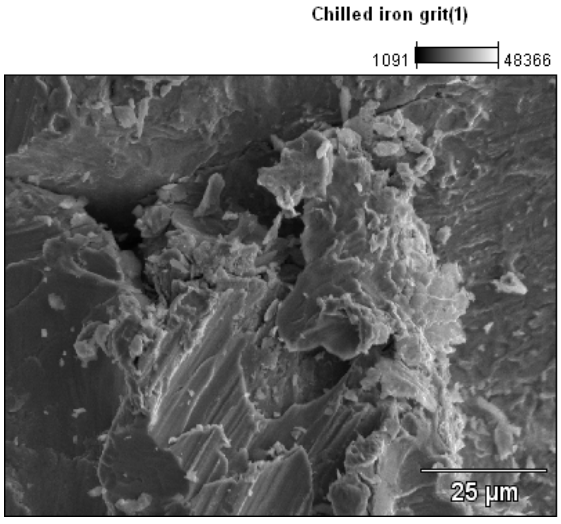


EDX Spectra of particle (left)

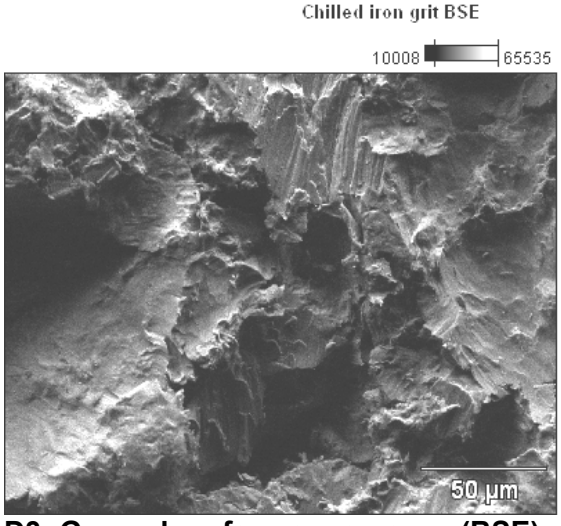
SEM INVESTIGATION OF COUPON BLASTED WITH CHILLED IRON GRIT



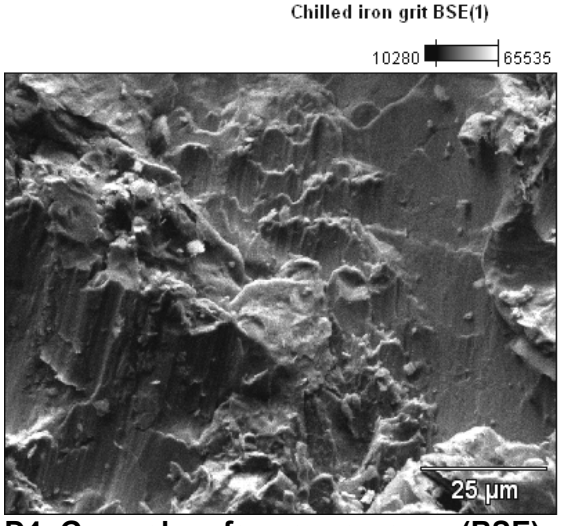
D1: General surface appearance Magnification x500



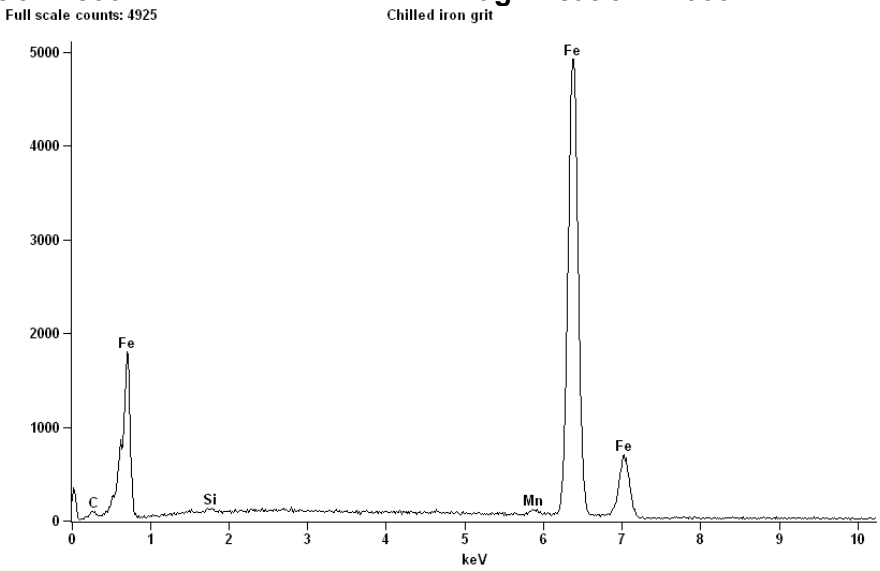
D2: General surface appearance Magnification x1000



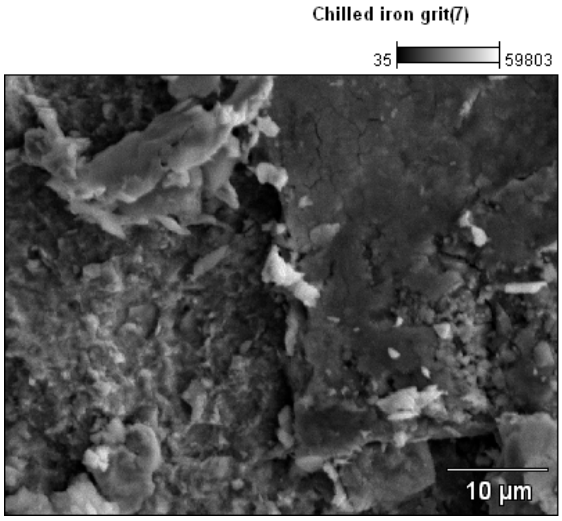
D3: General surface appearance (BSE) Magnification x500



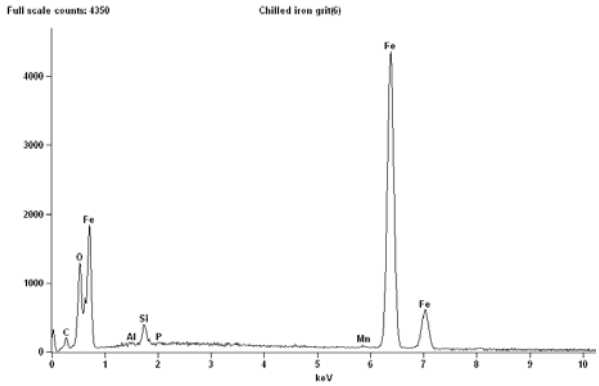
D4: General surface appearance (BSE) Magnification x1000



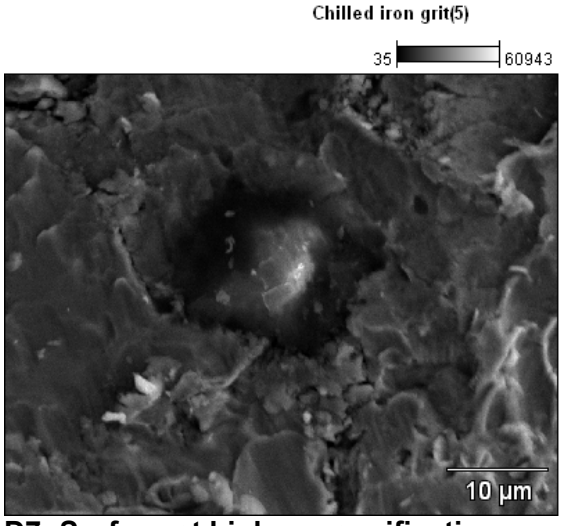
D5: EDX Spectra of general surface



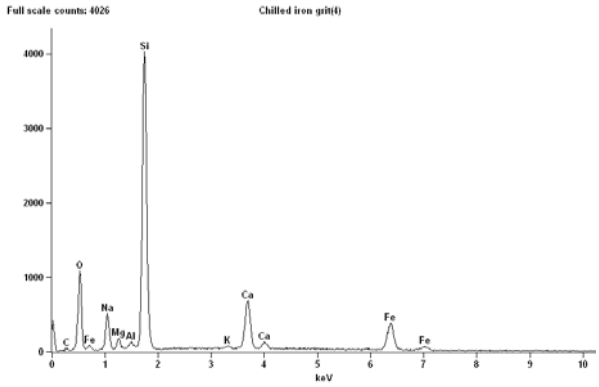
D6: Surface at higher magnification, x2000



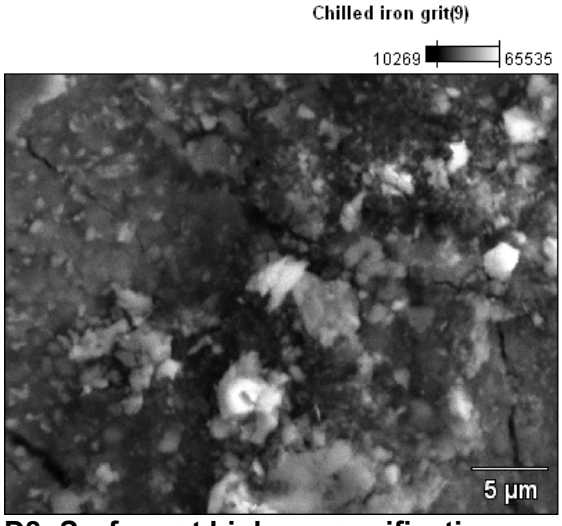
EDX Spectra of particle (left)



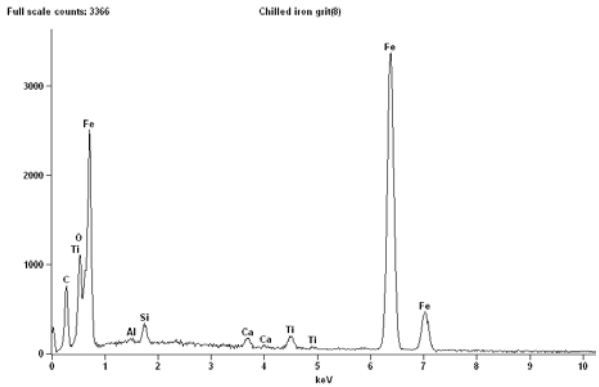
D7: Surface at higher magnification, x2000



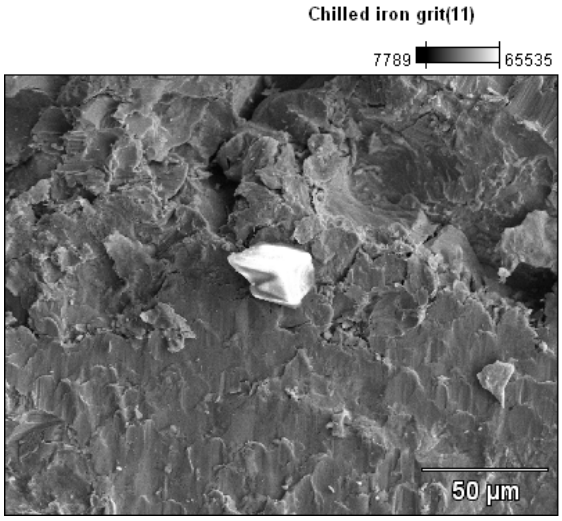
EDX Spectra of particle (left)



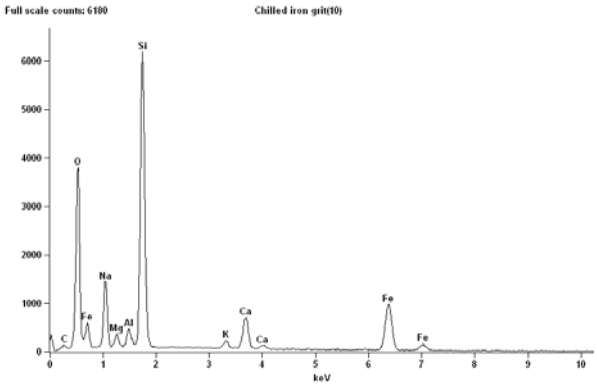
D8: Surface at higher magnification, x3000



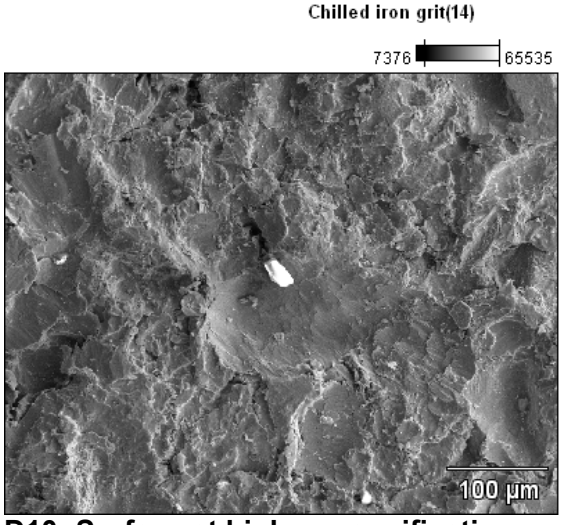
EDX Spectra of particle (left)



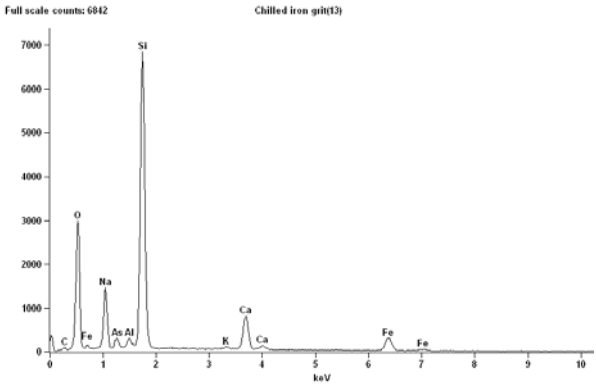
D9: Surface at higher magnification, x500



EDX Spectra of particle (left)

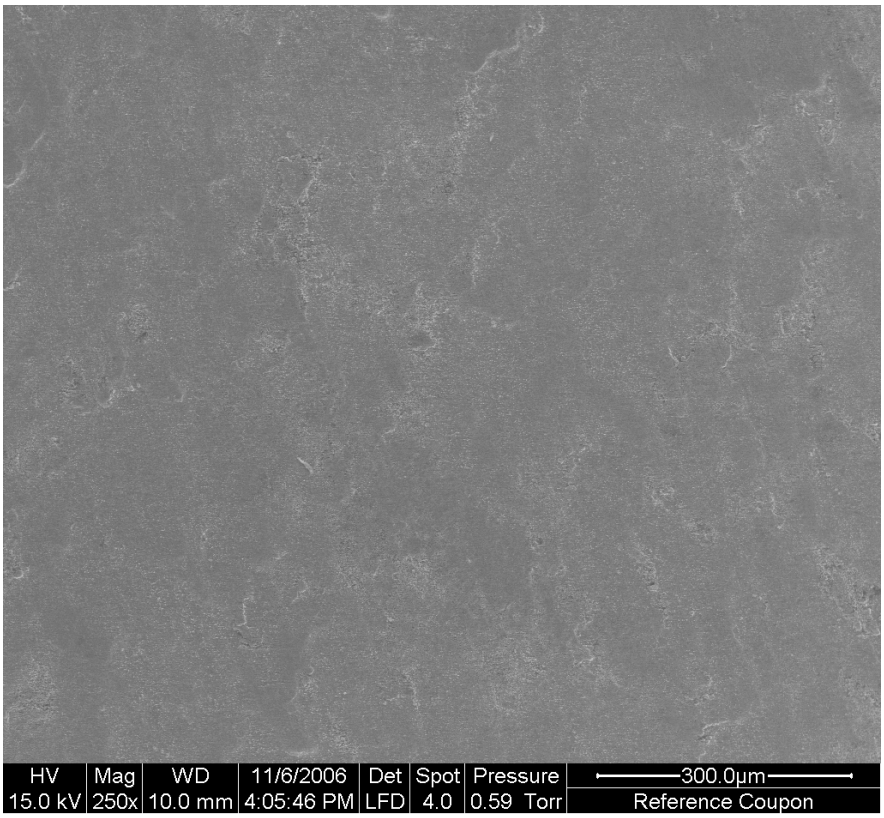


D10: Surface at higher magnification, x200

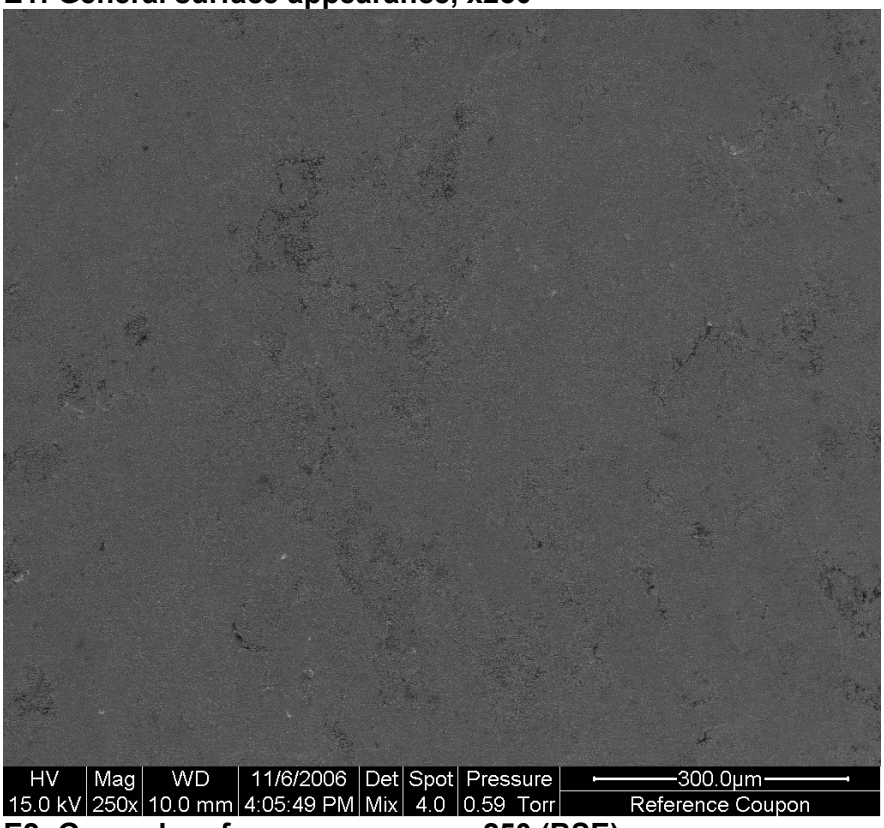


EDX Spectra of particle (left)

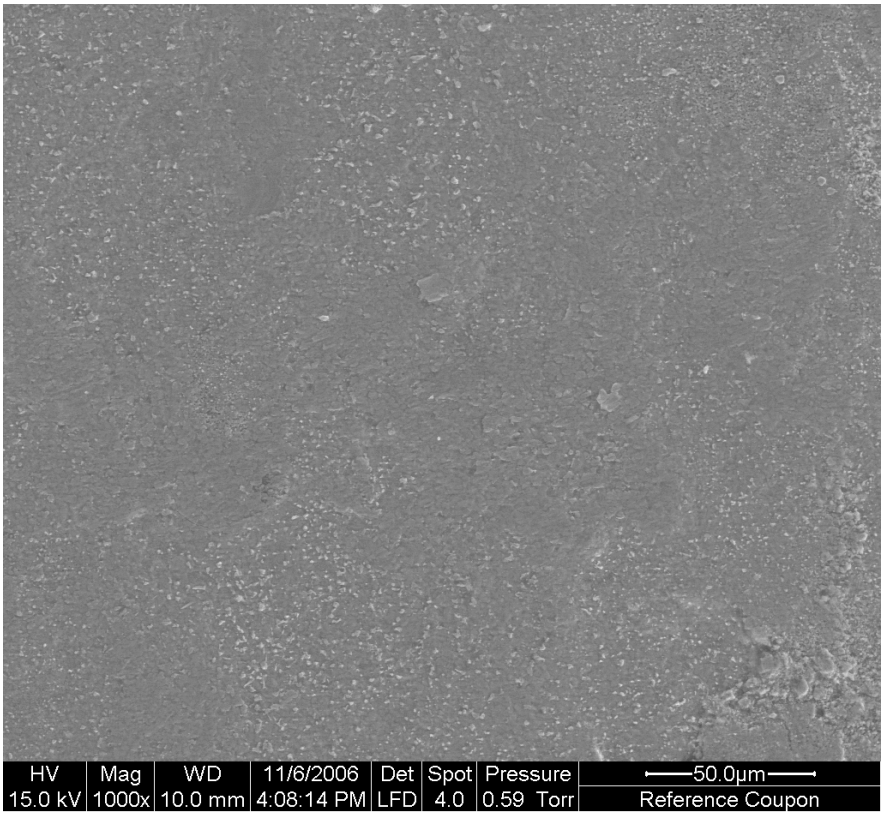
ESEM INVESTIGATION OF THE REFERENCE COUPON



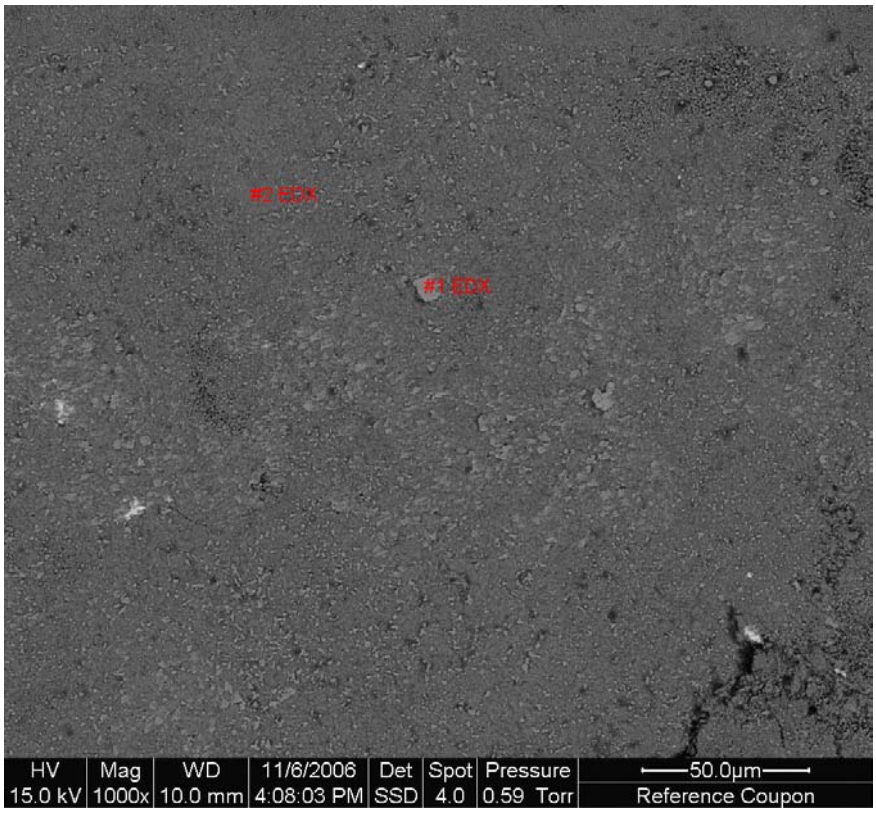
E1: General surface appearance, x250



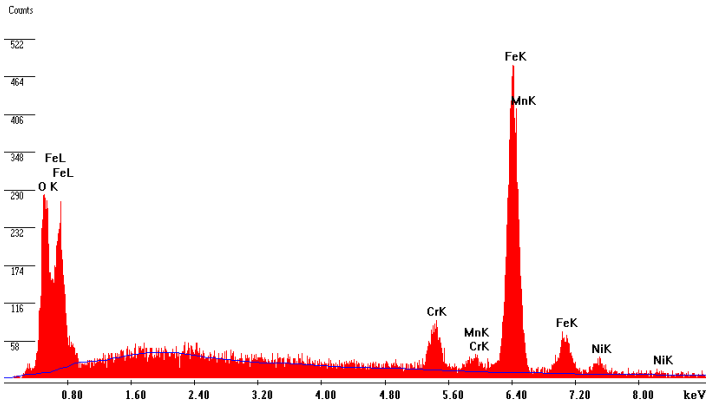
E2: General surface appearance, x250 (BSE)



E3: General surface appearance, x1000

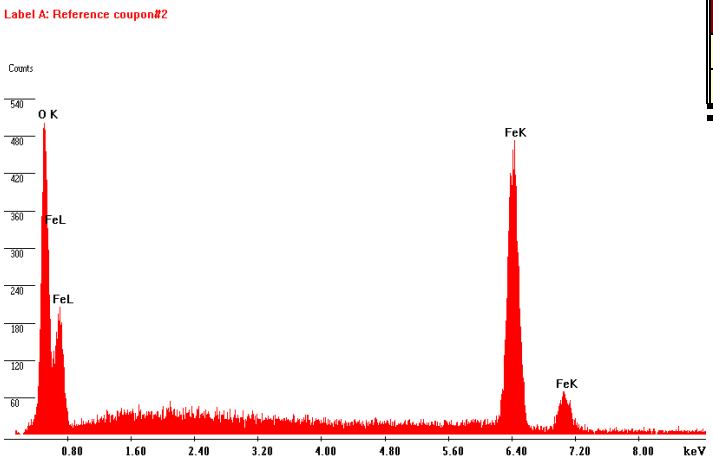


E4: Surface at higher magnification, x1000



Element	Wt %	At%
O	9.21	26.10
Cr	6.61	5.76
Mn	2.30	1.90
Fe	75.81	61.55
Ni	6.07	4.69

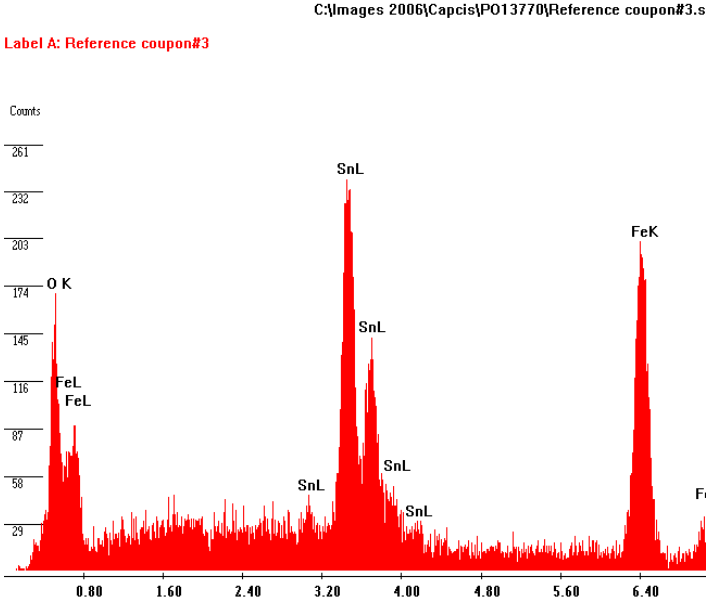
E5: EDX analysis of particle #1



Element	Wt %	At%
O	16.12	40.14
Fe	83.88	59.86

E6: EDX analysis of the general surface

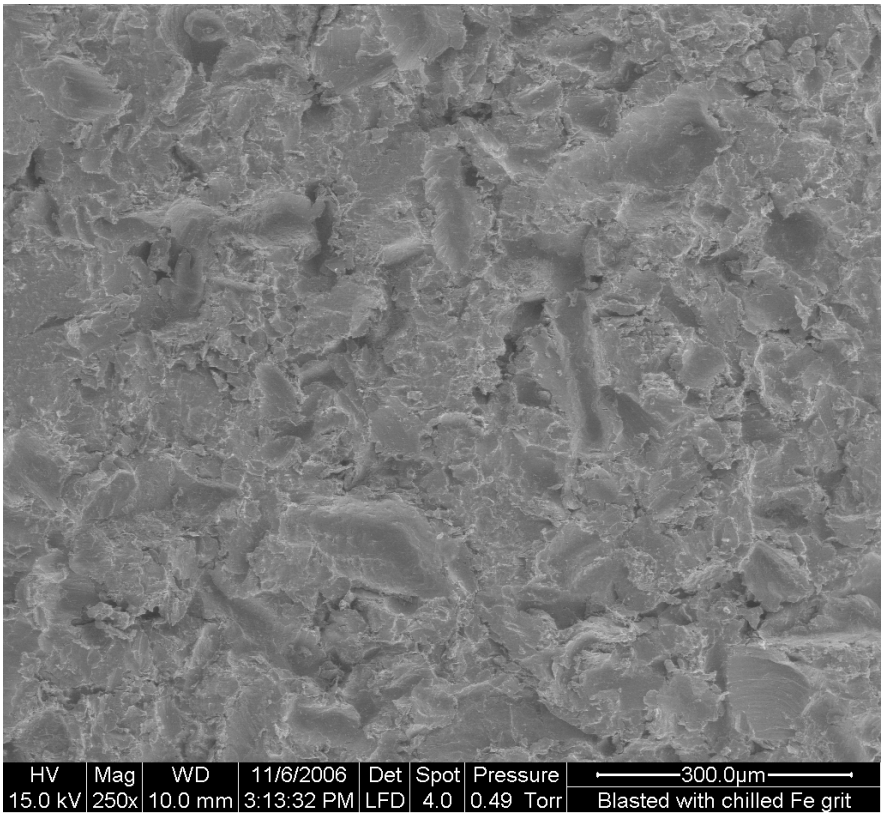
E7: Surface at higher magnification, x4000



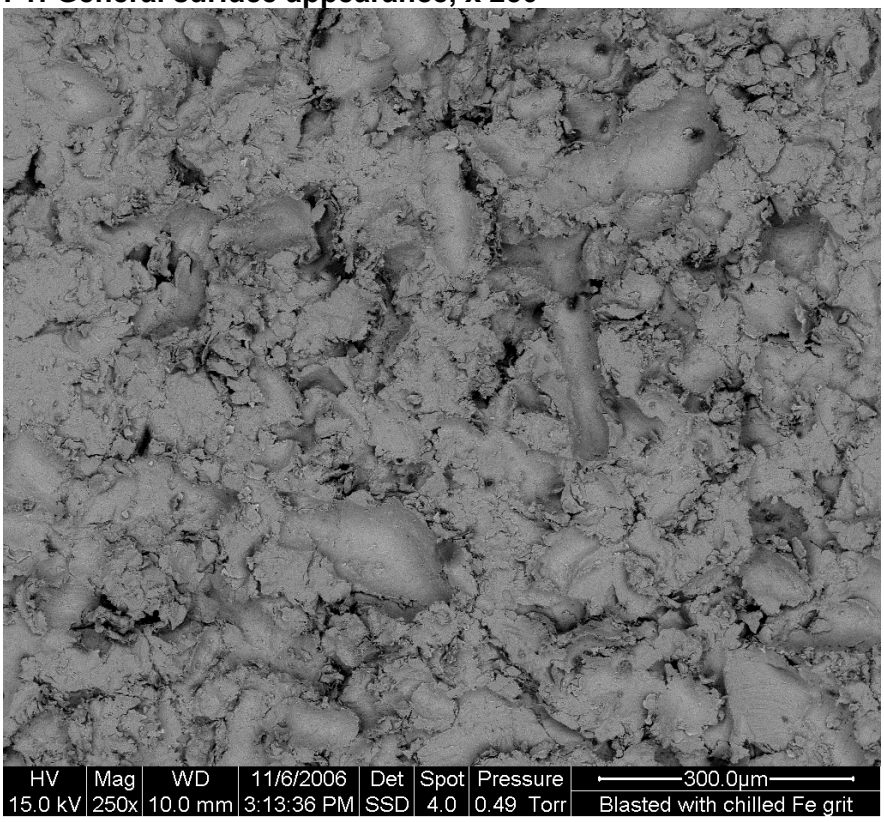
Element	Wt %	At %
O	12.96	40.82
Sn	40.52	17.20
Fe	46.52	41.98

E8: EDX analysis of particle #3

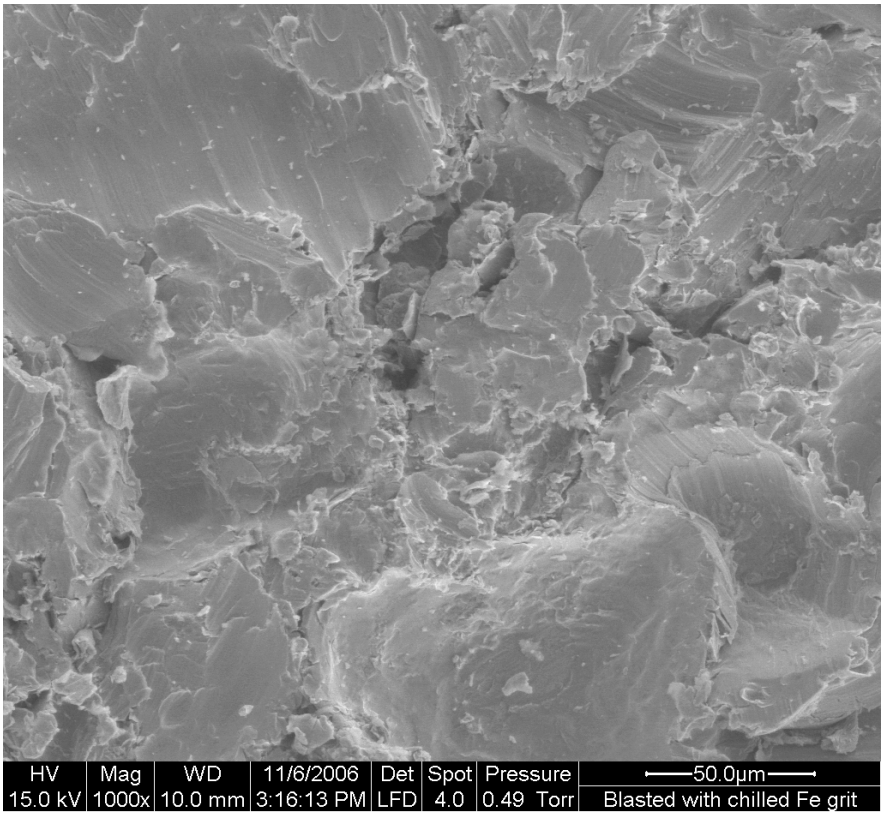
ESEM INVESTIGATION OF A COUPON BLASTED WITH CHILLED IRON GRIT



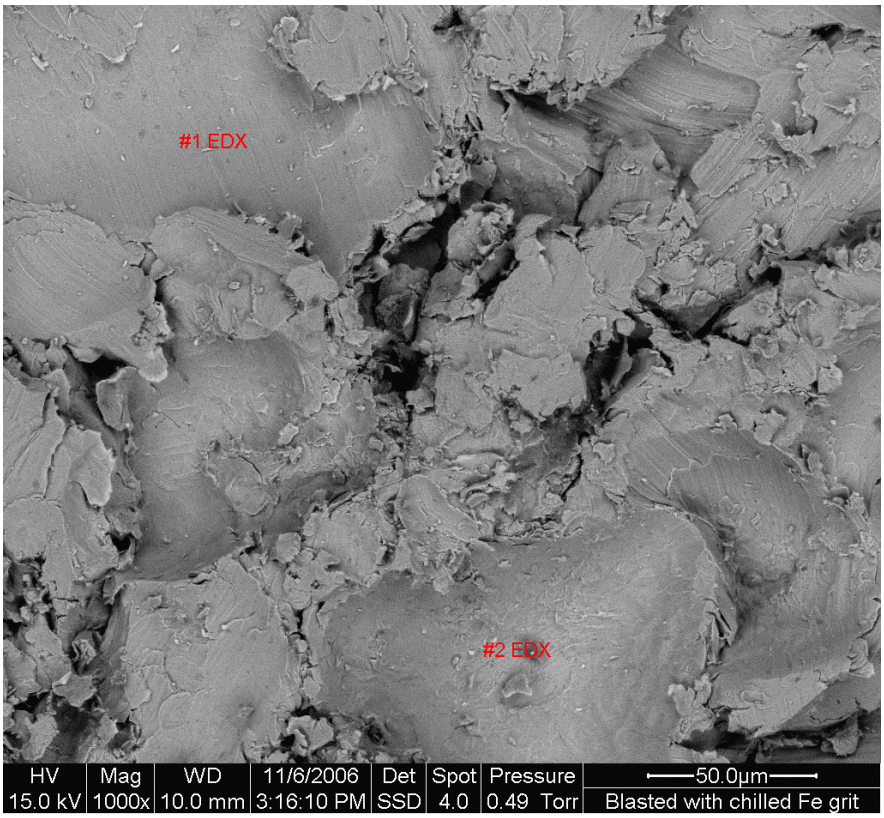
F1: General surface appearance, x 250



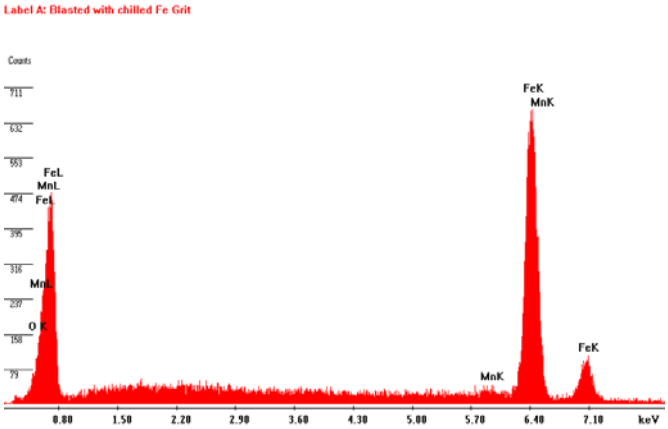
F2: General surface appearance, x 250 (BSE)



F3: Surface at higher magnification, x1000

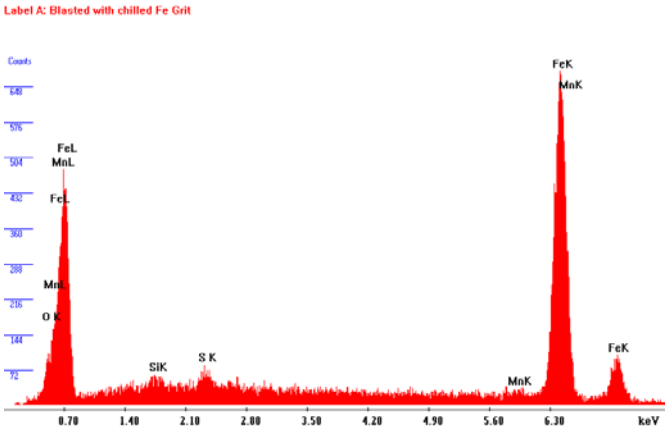


F4: Surface at higher magnification, x1000



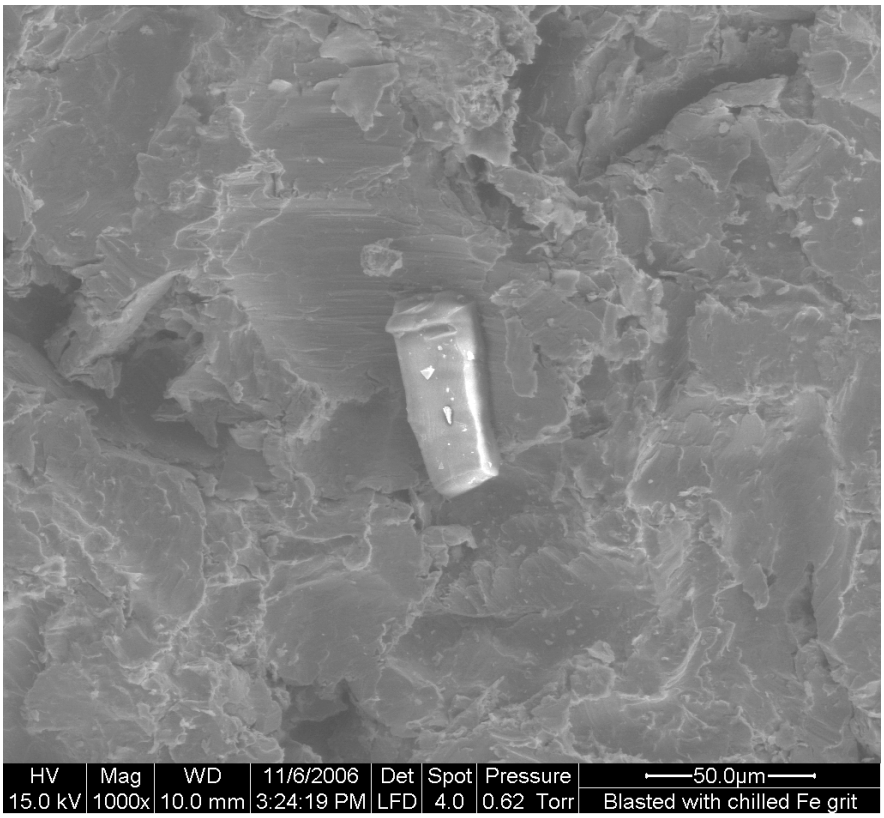
Element	Wt %	At%
Mn	3.03	3.08
Fe	96.97	96.92

F5: EDX analysis of the general surface

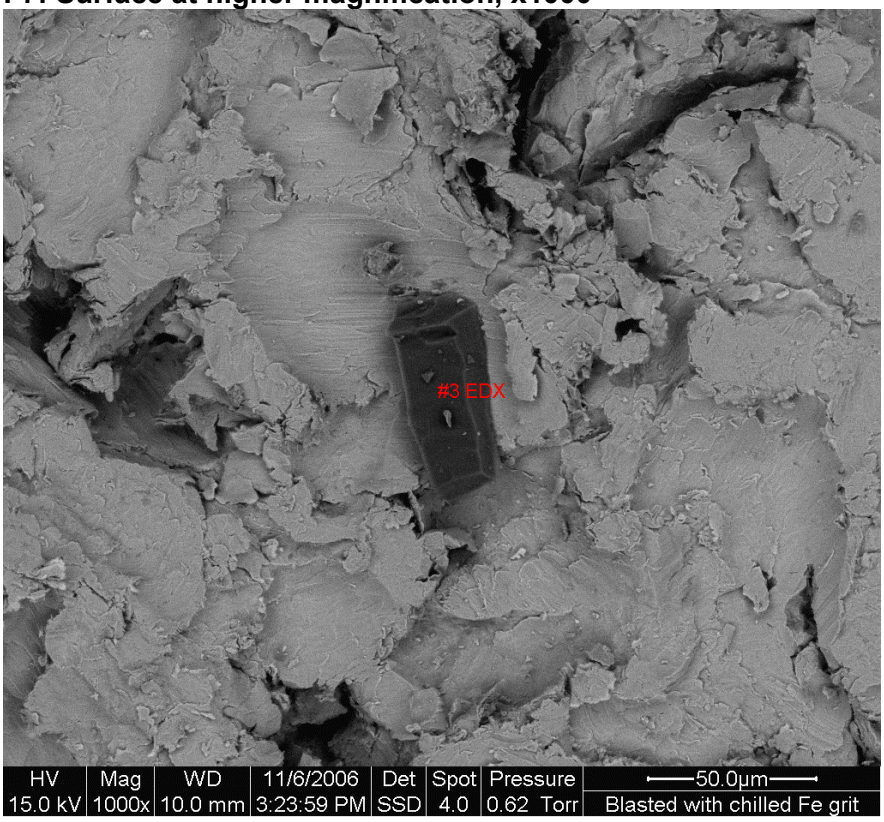


Element	Wt %	At%
Si	0.64	1.25
S	1.07	1.84
Mn	2.21	2.21
Fe	96.08	94.69

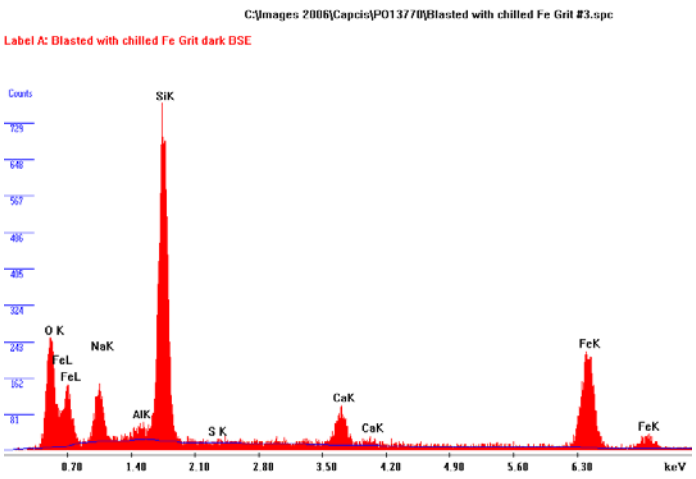
F6: EDX analysis of particle #2



F7: Surface at higher magnification, x1000

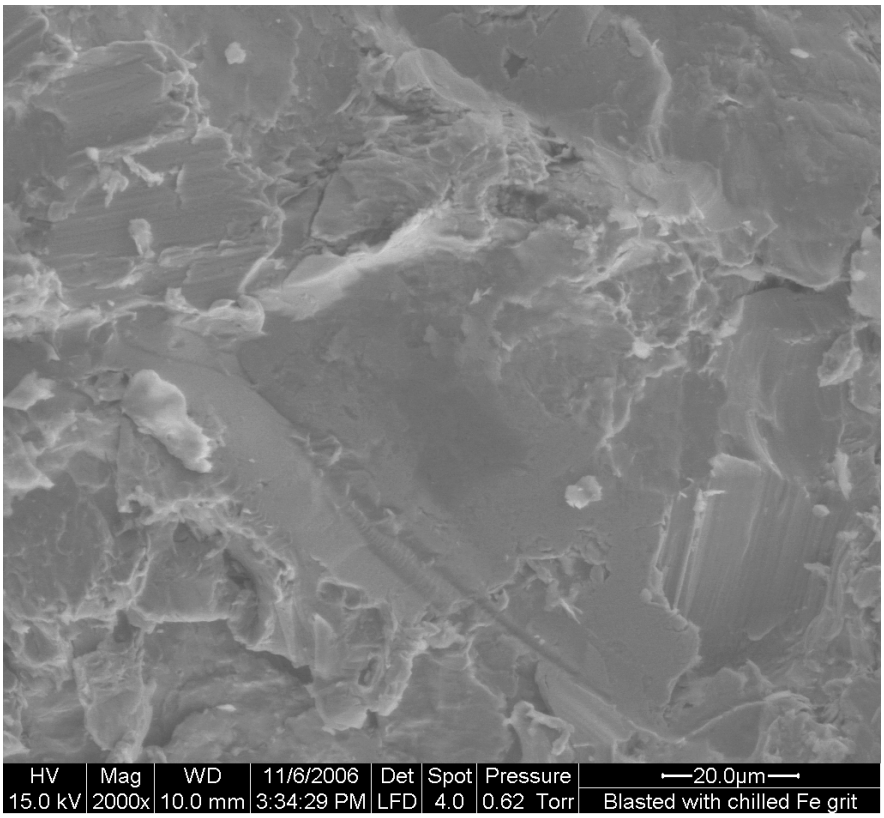


F8: Surface at higher magnification, x1000 (BSE)

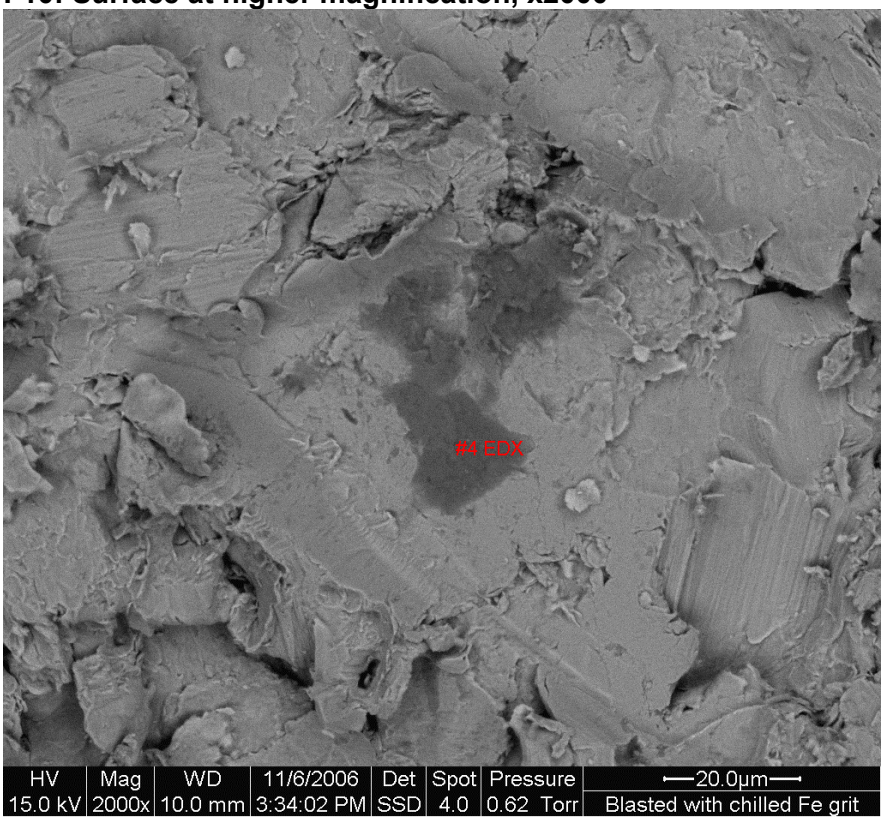


Element	Wt %	At %
O	13.84	27.74
Na	7.43	10.37
Al	1.34	1.59
Si	25.87	29.54
S	0.20	0.20
Ca	4.82	3.86
Fe	46.50	26.70

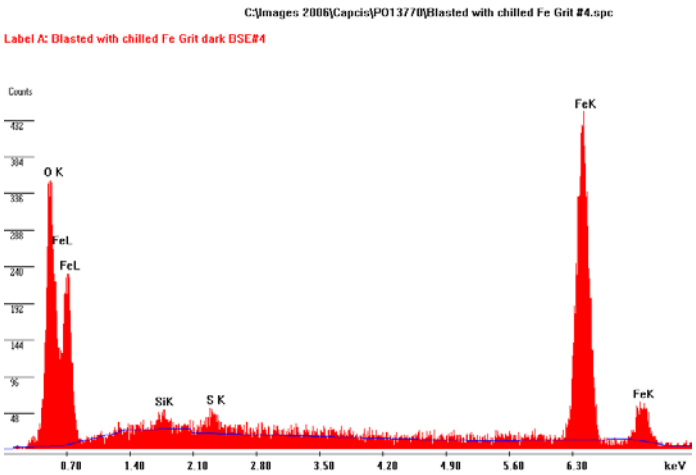
F9: EDX analysis of particle #3



F10: Surface at higher magnification, x2000



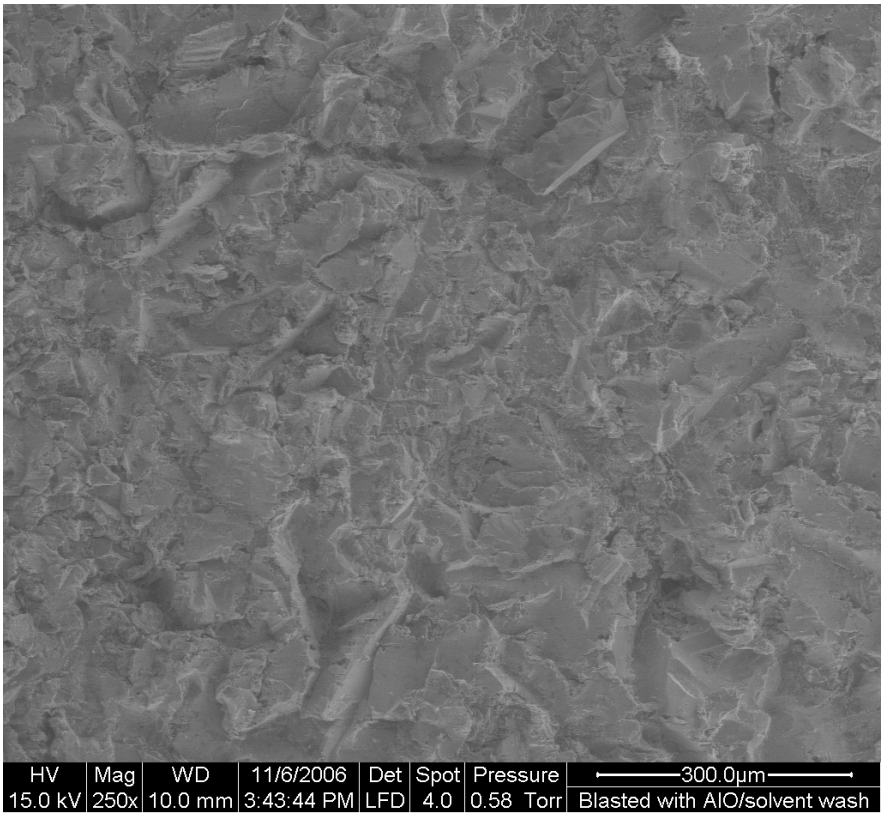
F11: Surface at higher magnification, x2000 (BSE) (stain is probably residual mill scale)



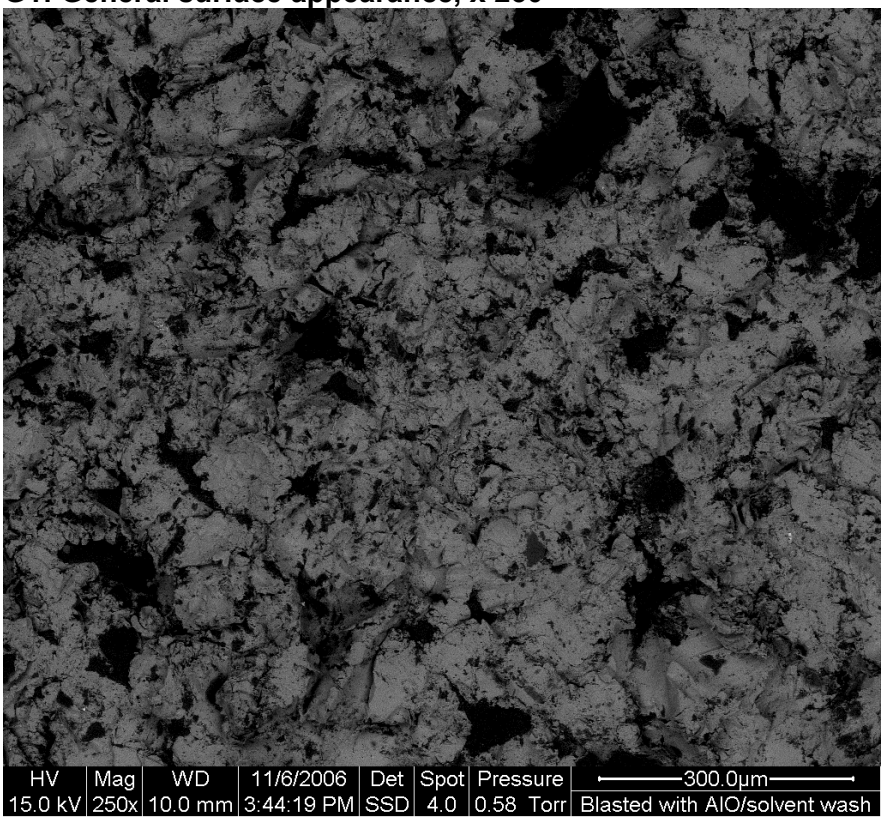
Element	Wt %	At %
O	14.03	35.82
Si	0.88	1.29
S	1.19	1.52
Fe	83.89	61.37

F12: EDX analysis of particle #4

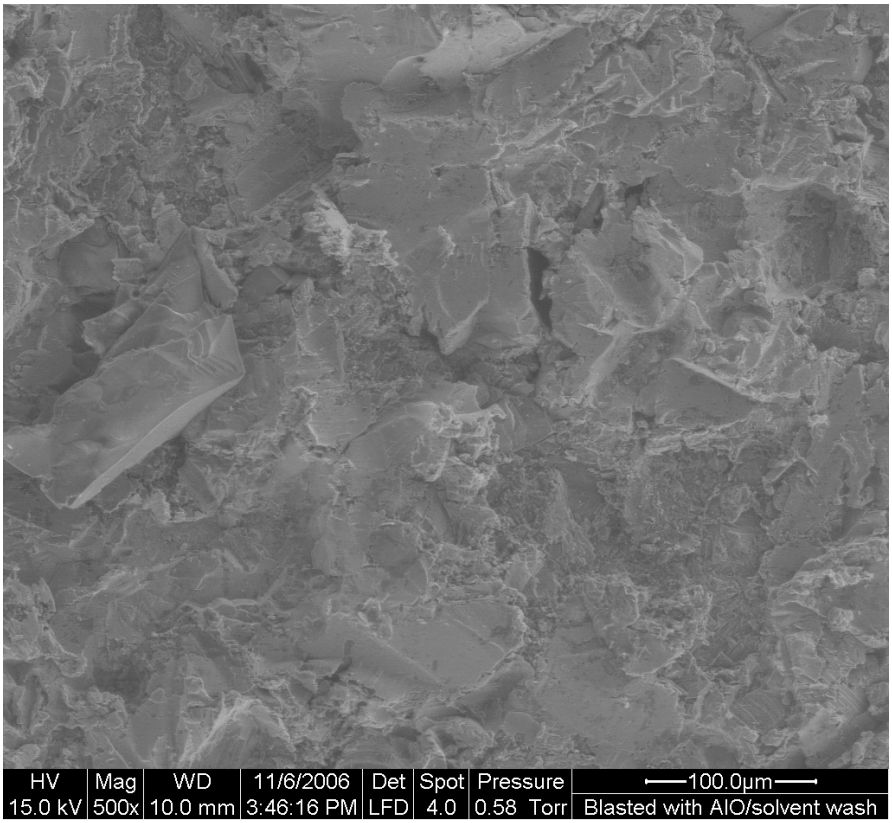
ESEM INVESTIGATION OF COUPON BLASTED WITH ALUMINIUM OXIDE WITH SOLVENT WASH



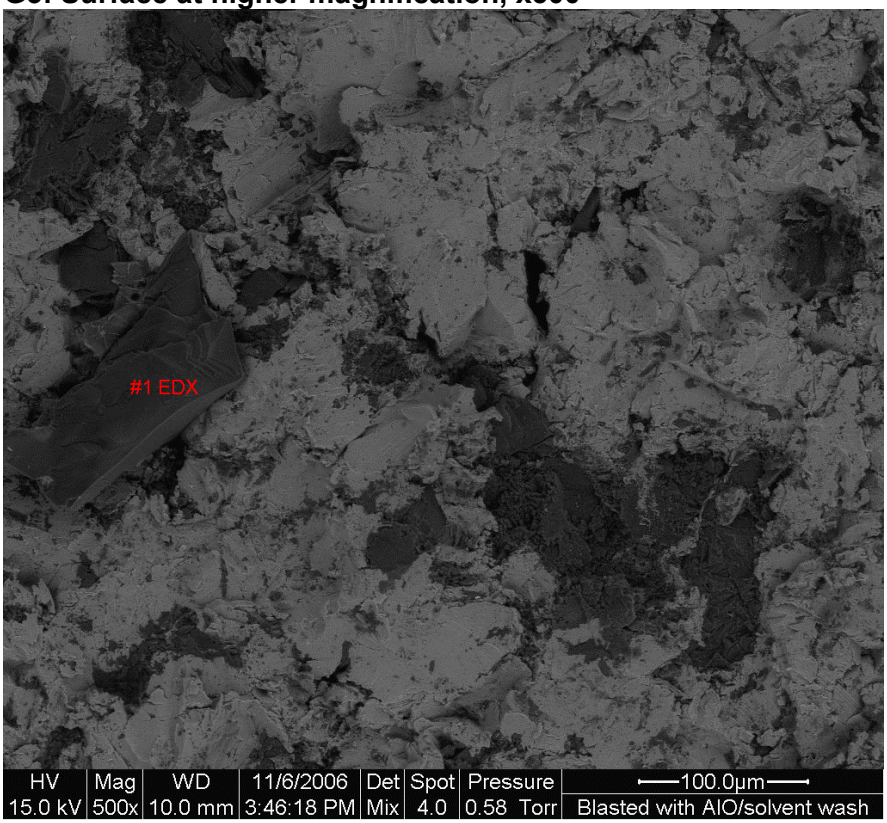
G1: General surface appearance, x 250



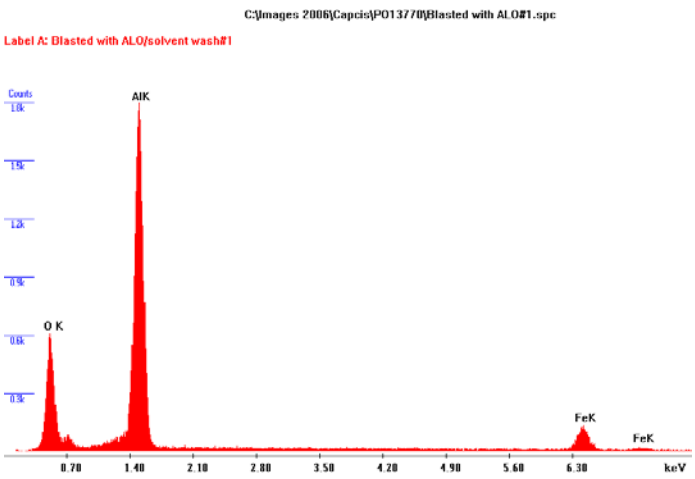
G2: General surface appearance, x 250 (BSE)



G3: Surface at higher magnification, x500

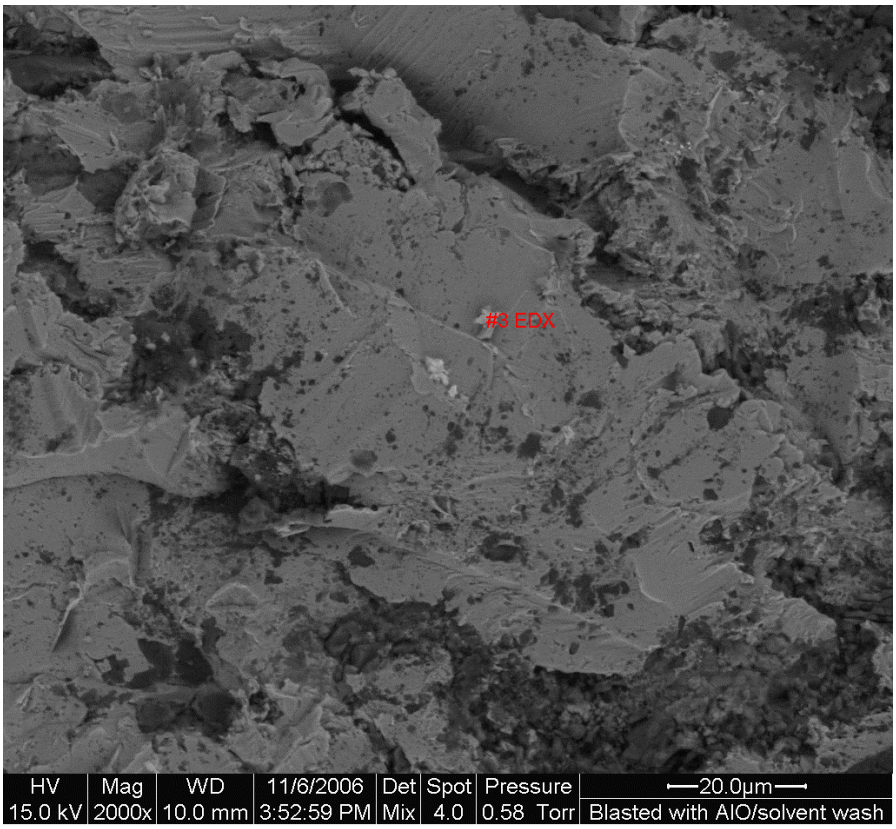


G4: Surface at higher magnification, x500 (BSE)

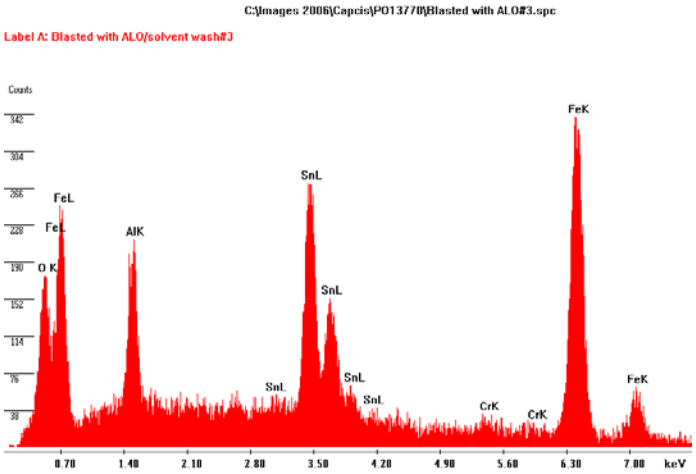


Element	Wt %	At%
O	24.97	40.05
Al	51.80	49.27
Fe	23.24	10.68

G5: EDX analysis of the general surface



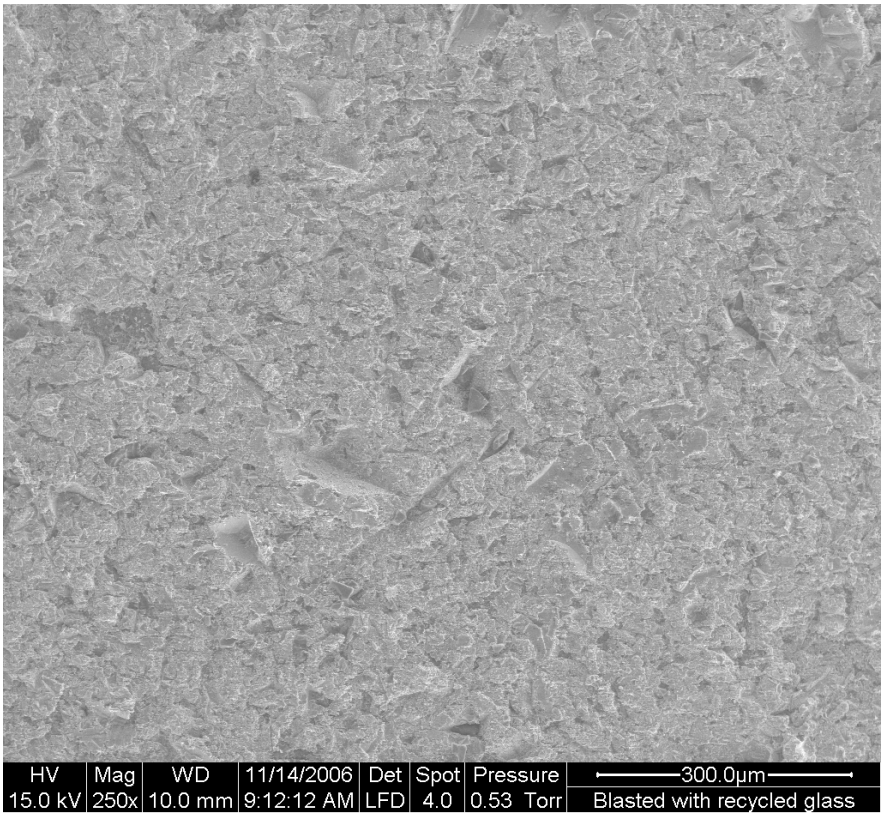
G6: Surface at higher magnification, x2000



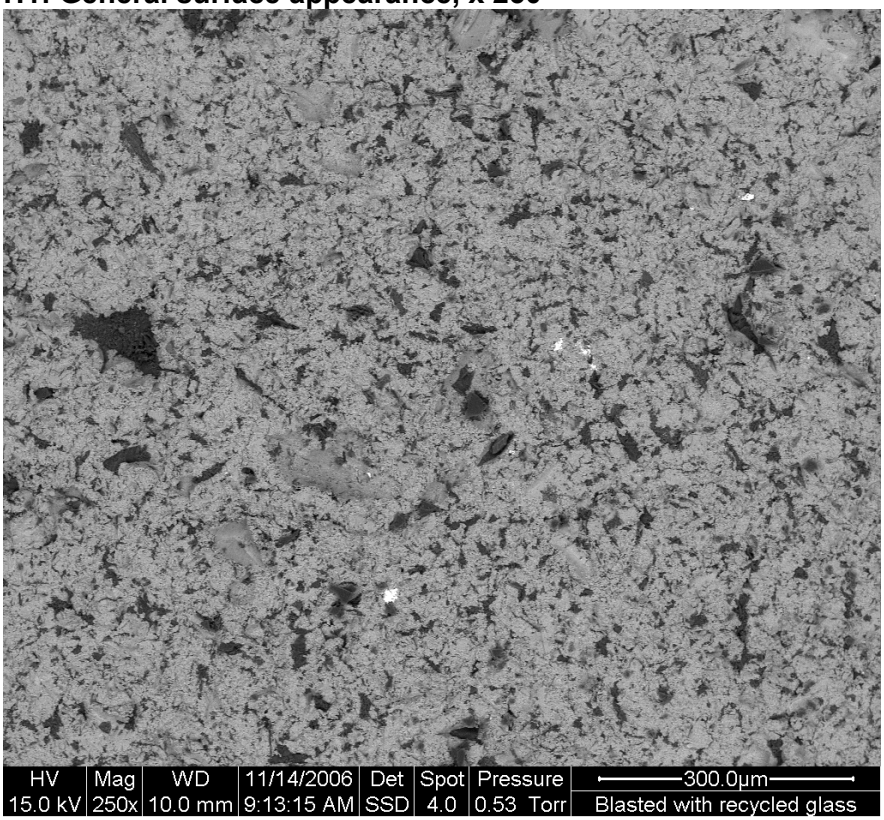
Element	Wt %	At %
O	9.31	28.45
Al	6.05	10.96
Sn	29.22	12.03
Cr	1.08	1.02
Fe	54.33	47.54

G7: EDX analysis of particle #3

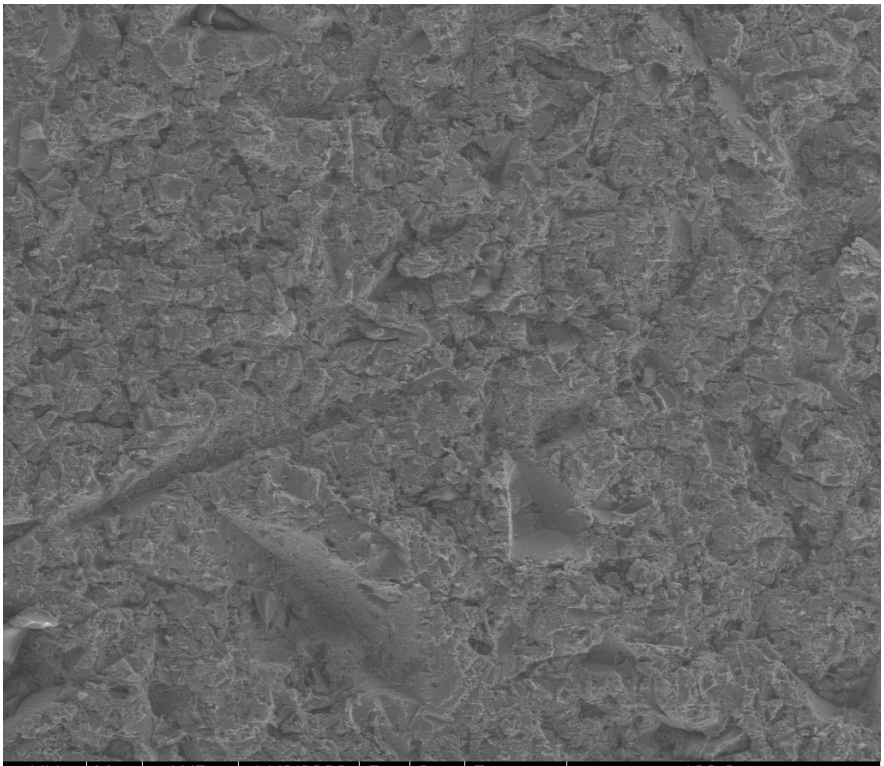
ESEM INVESTIGATION OF COUPON BLASTED RECYCLED GLASS



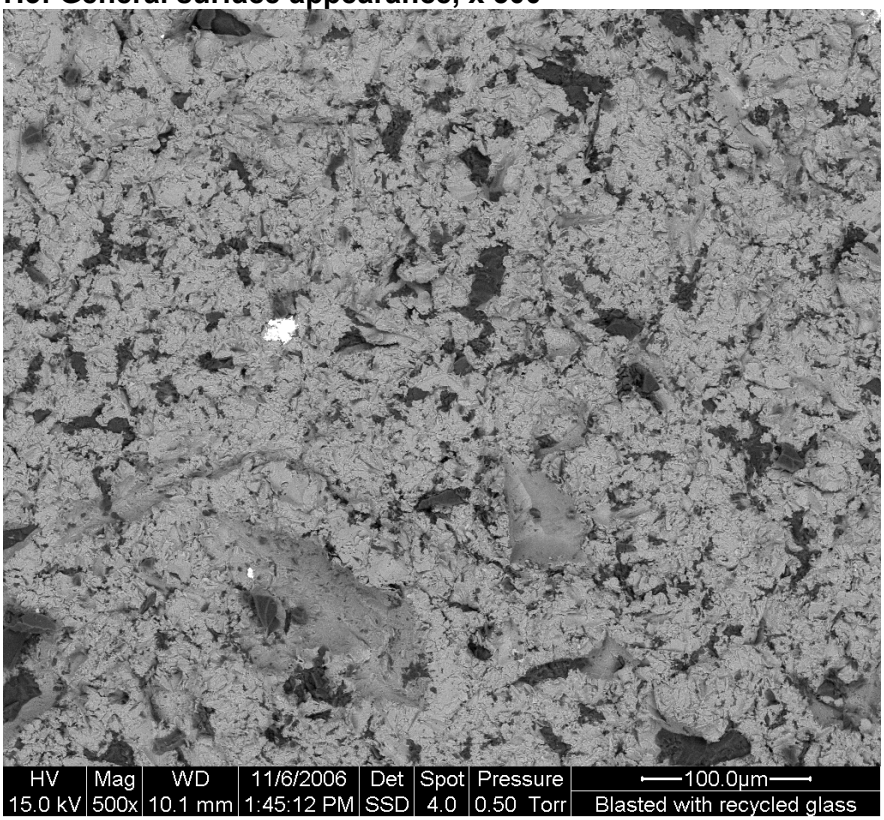
H1: General surface appearance, x 250



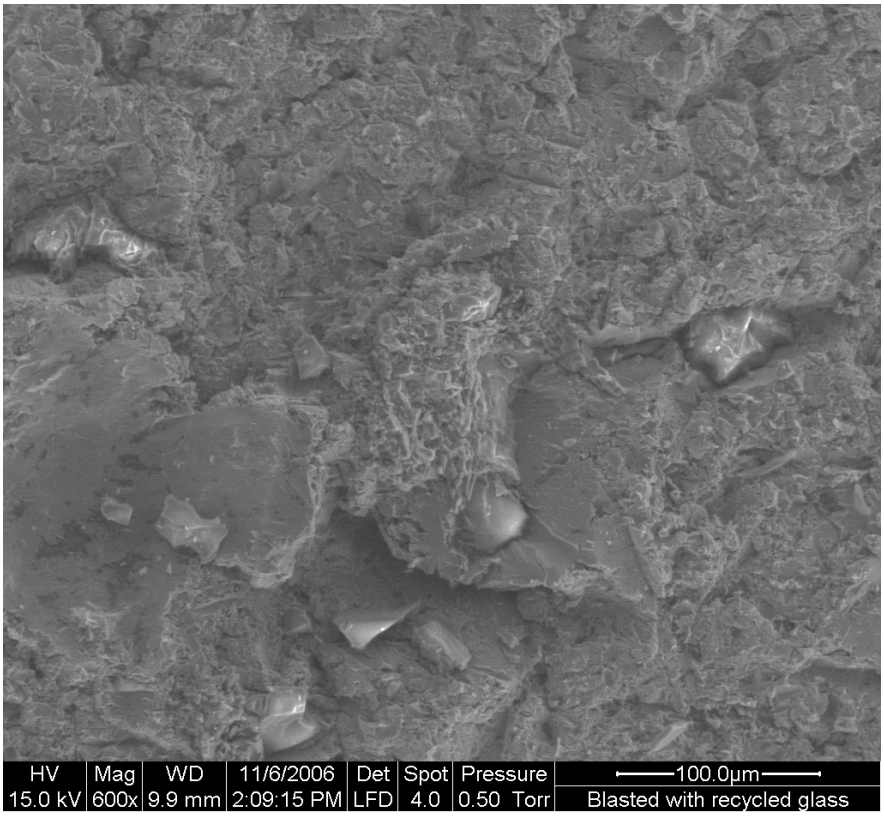
H2: General surface appearance, x 250 (BSE) (White spots are lead based particles)



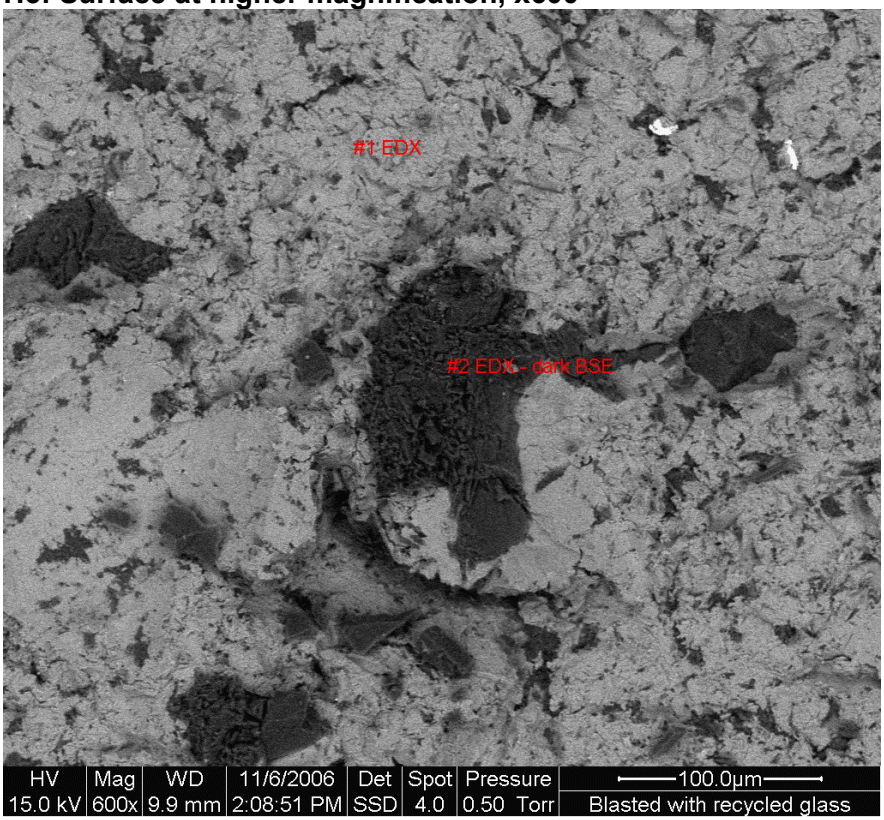
H3: General surface appearance, x 500



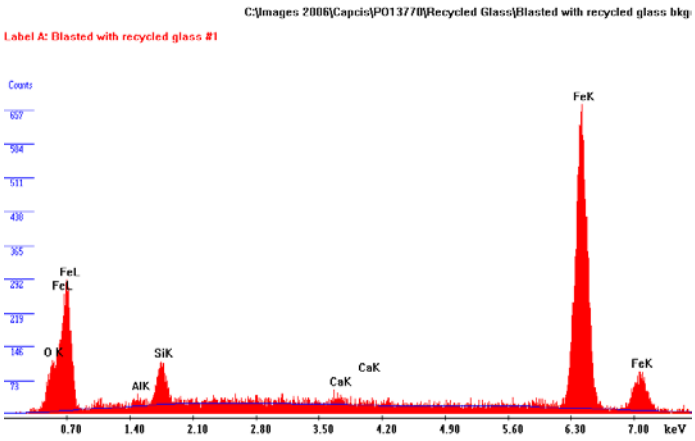
H4: General surface appearance, x 500 (BSE)



H5: Surface at higher magnification, x600

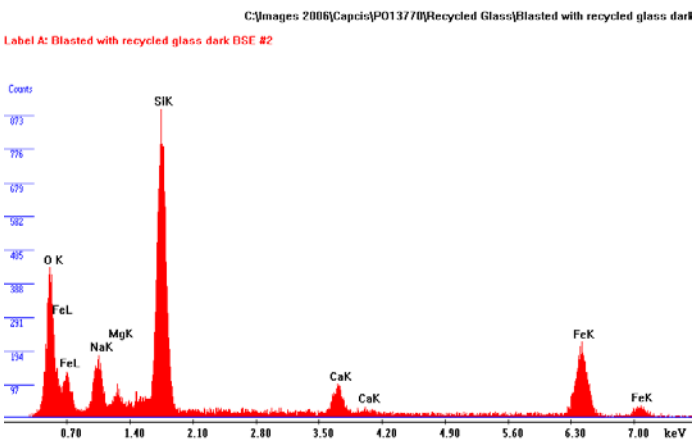


H6: Surface at higher magnification, x600 (BSE)



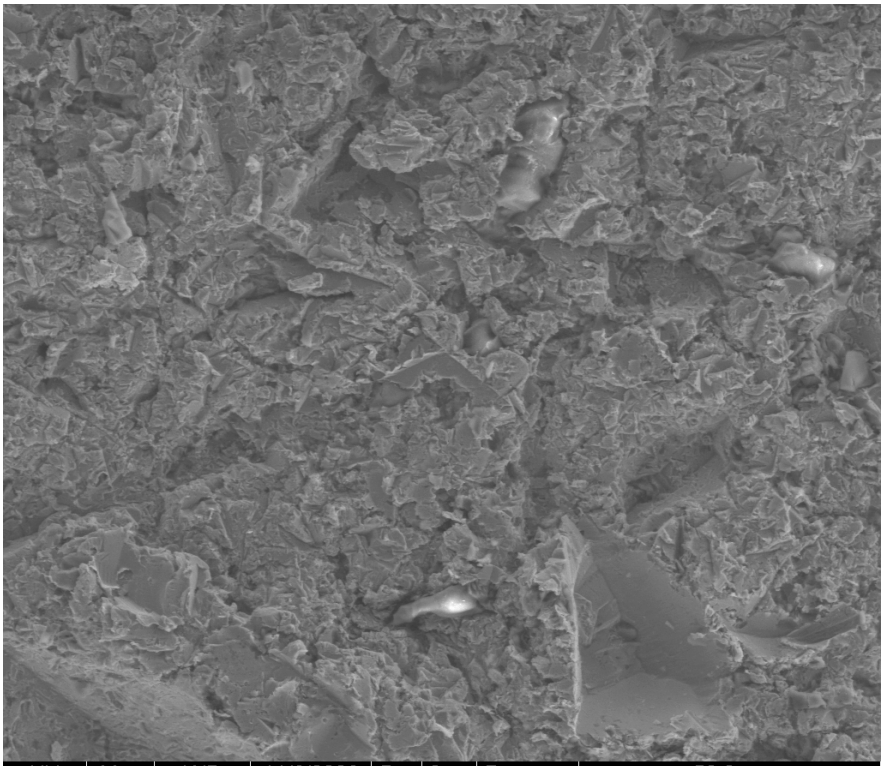
Element	Wt %	At%
O	3.13	9.80
Al	0.65	1.20
Si	2.77	4.94
Ca	0.86	1.07
Fe	92.59	82.99

H7: EDX analysis of the general surface

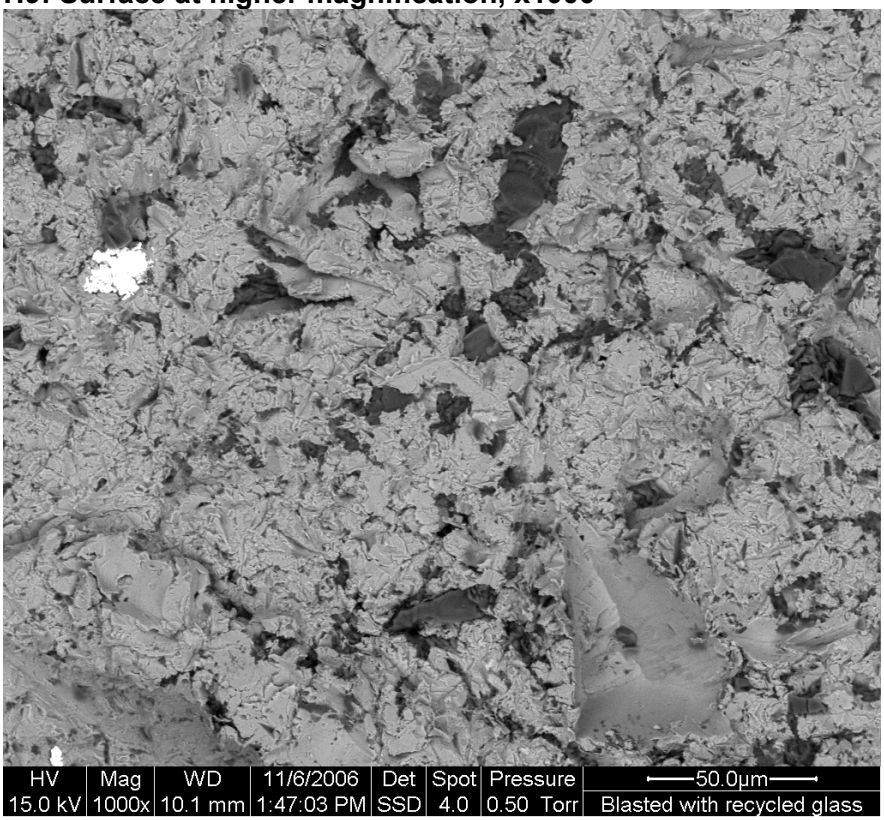


Element	Wt %	At%
O	21.05	37.98
Na	7.51	9.42
Mg	1.56	1.85
Si	26.76	27.50
Ca	4.70	3.38
Fe	38.43	19.87

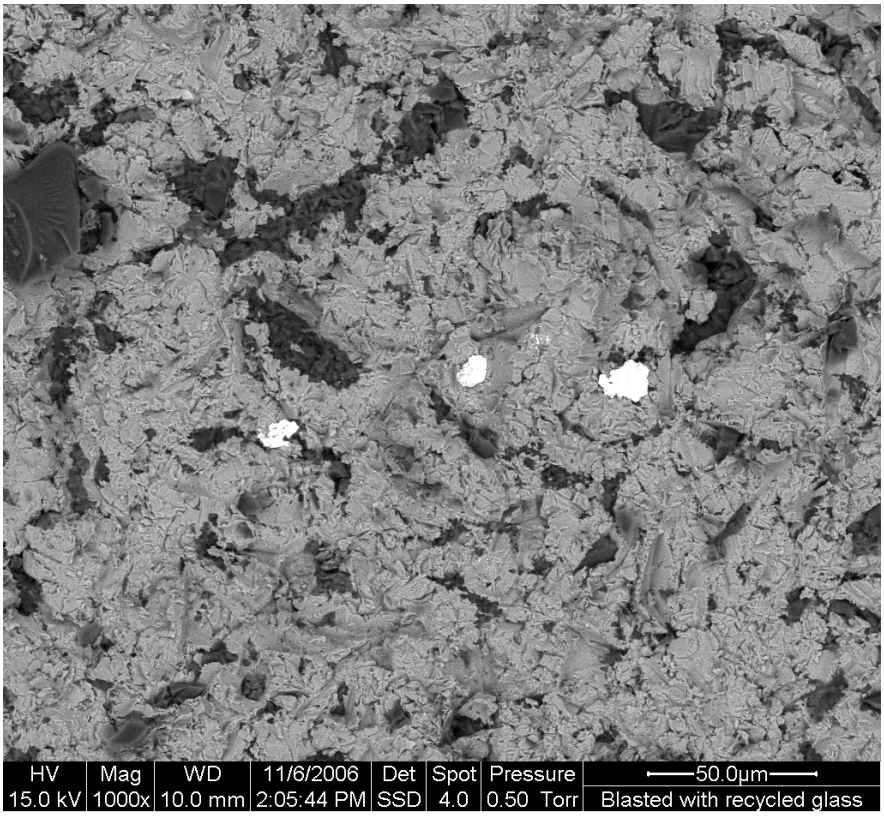
H8: EDX analysis of particle #2



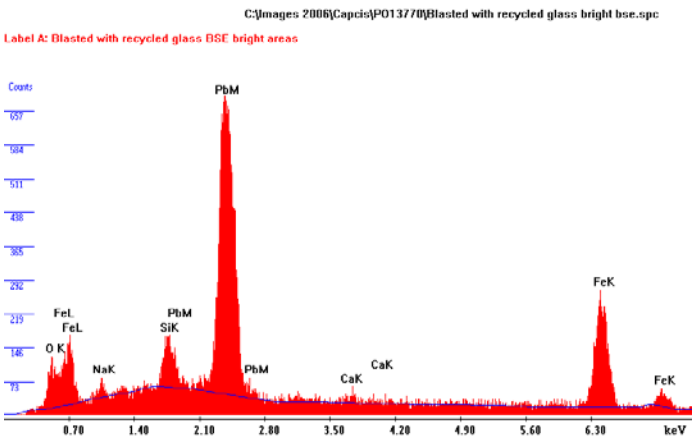
H9: Surface at higher magnification, x1000



H10: Surface at higher magnification, x1000 (BSE)

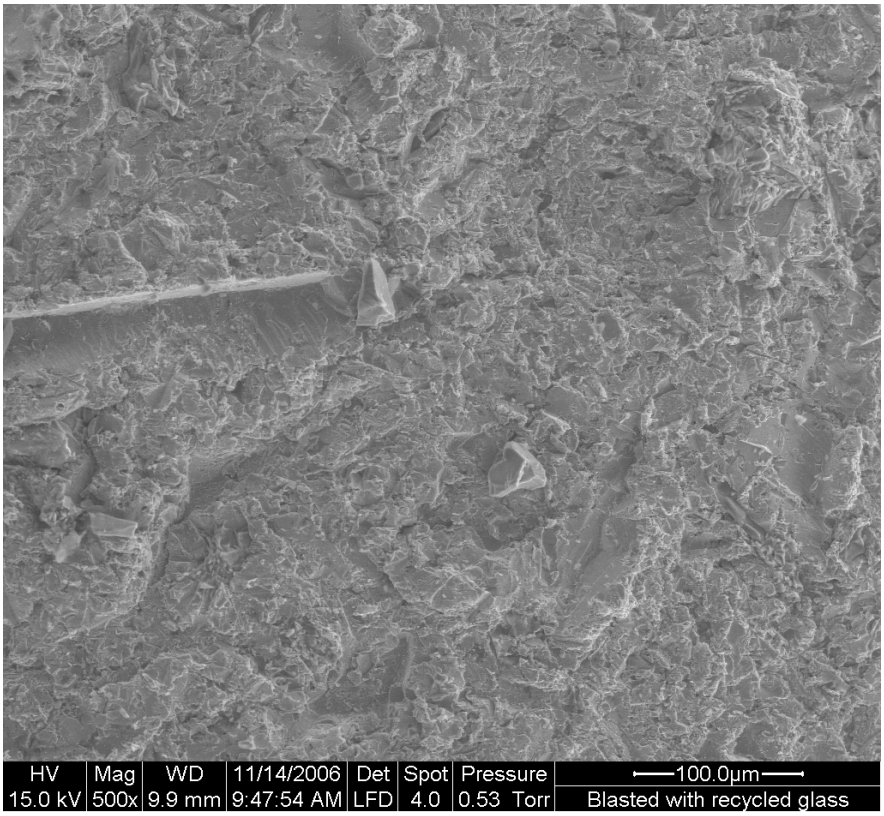


H11: Surface at higher magnification, x1000 (BSE)

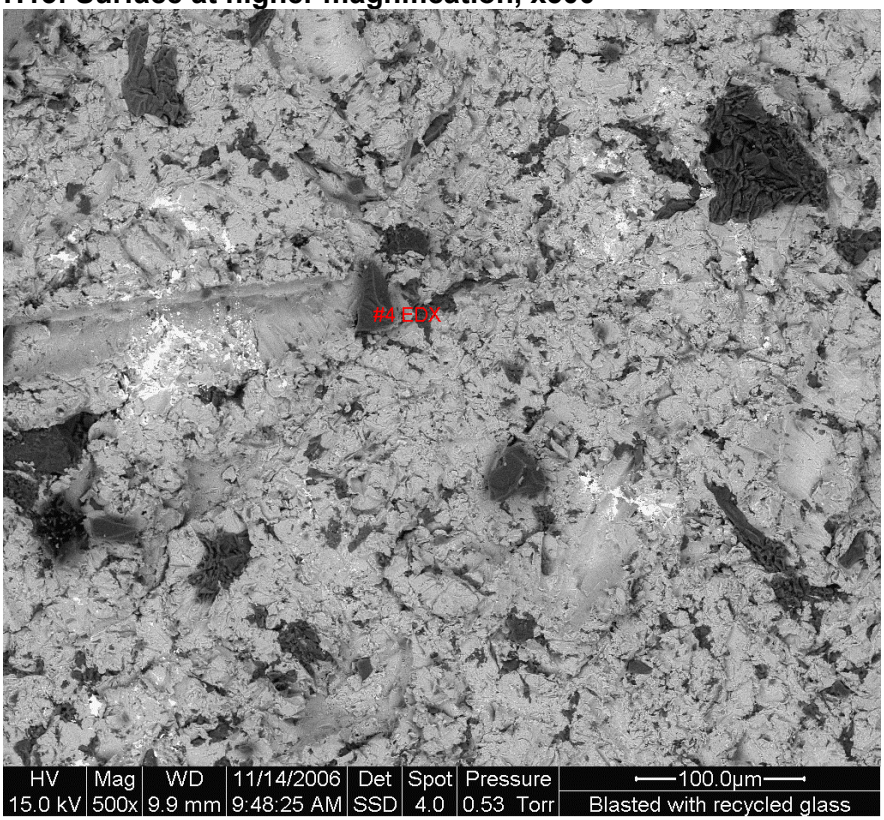


Element	Wt %	At %
O	5.19	23.90
Na	1.18	3.80
Mg	0.47	1.43
Si	2.53	6.63
Pb	57.89	20.59
Ca	0.86	1.59
Fe	31.87	42.06

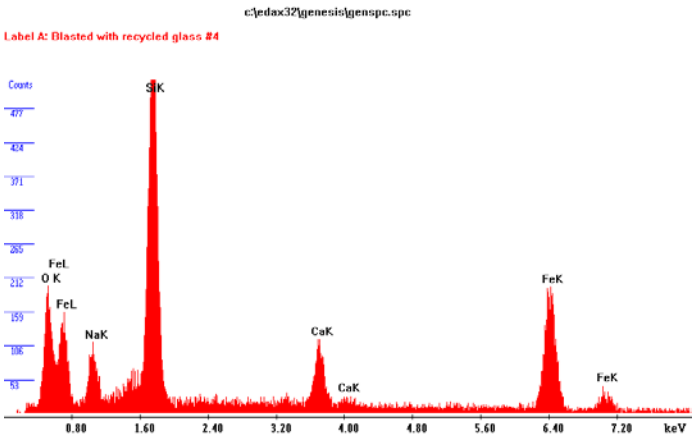
H12: EDX analysis of bright particle



H13: Surface at higher magnification, x500



H14: Surface at higher magnification, x500 (BSE)

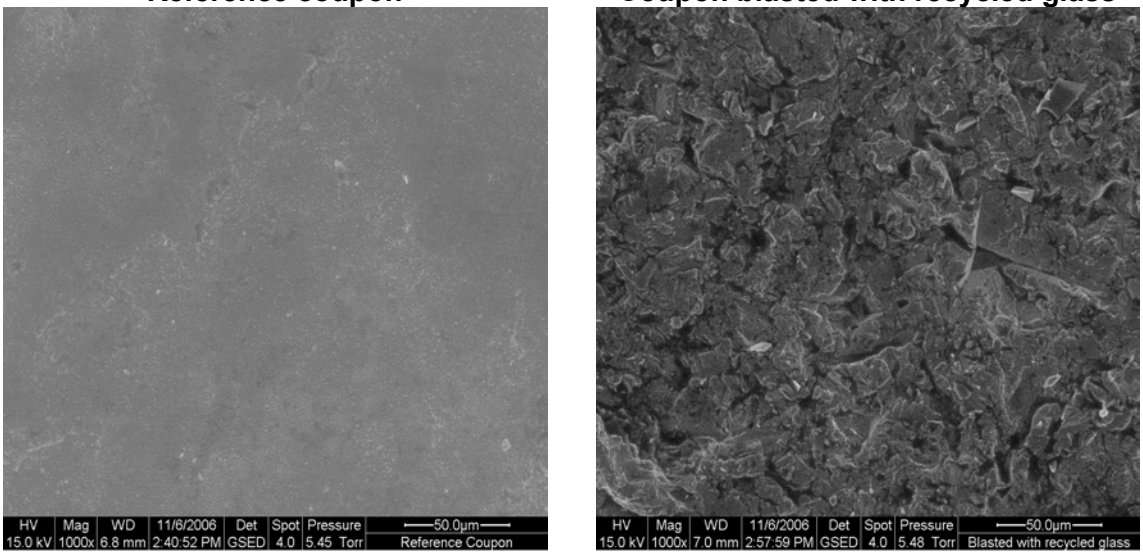


Element	Wt %	At %
O	30.92	45.95
Na	8.84	9.14
Al	2.28	2.01
Si	39.88	33.75
Ca	8.70	5.16
Fe	9.38	3.99

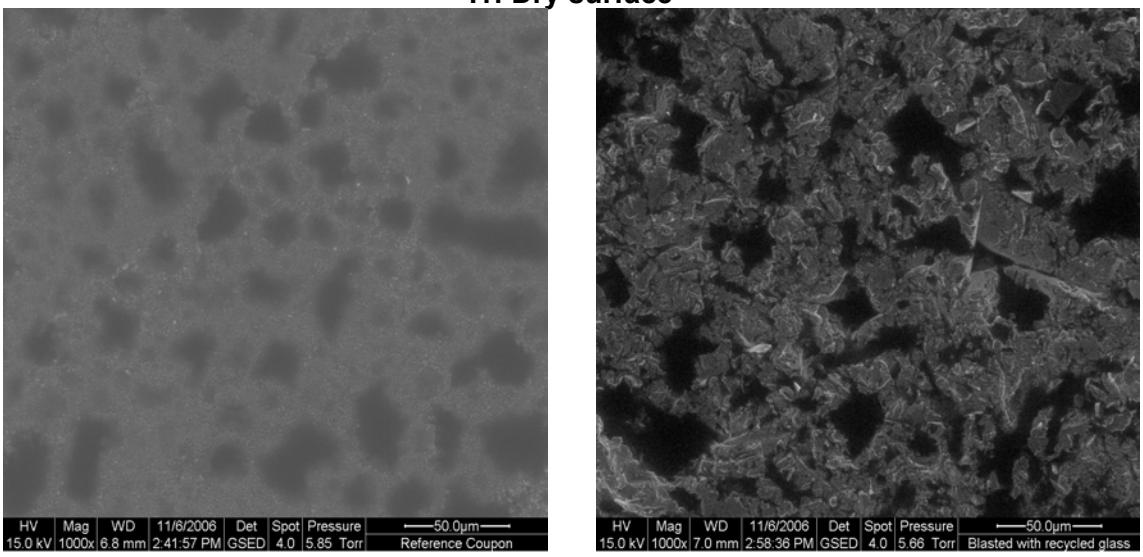
H15: EDX analysis of particle #4

SURFACE WETTING CHARACTERISTICS USING THE ESEM

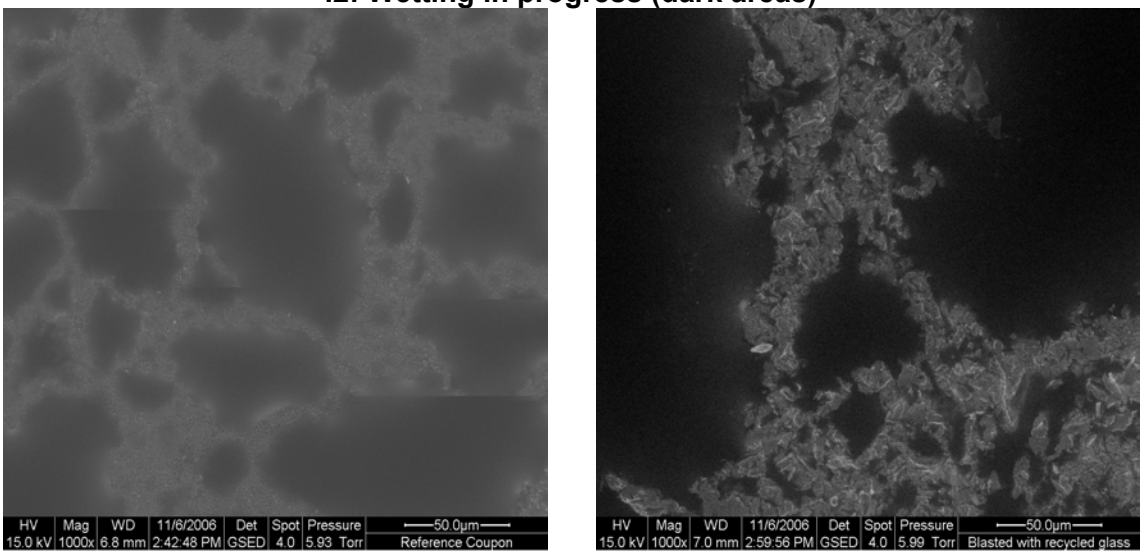
Reference coupon | **Coupon blasted with recycled glass**



I1: Dry surface

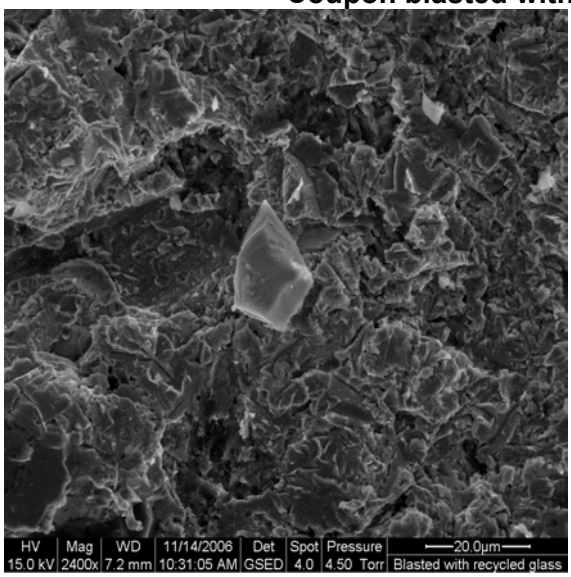


I2: Wetting in progress (dark areas)

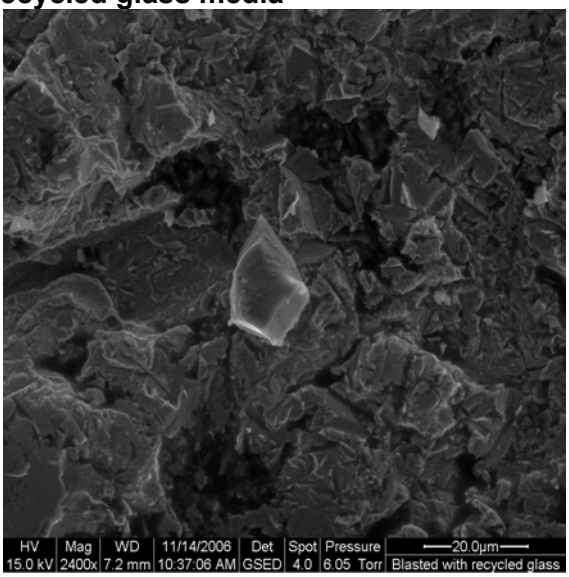


I3: Specimens partly flooded

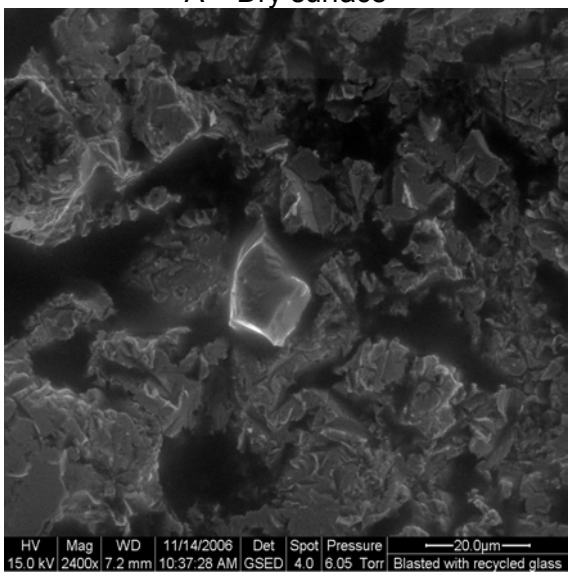
Coupon blasted with recycled glass media



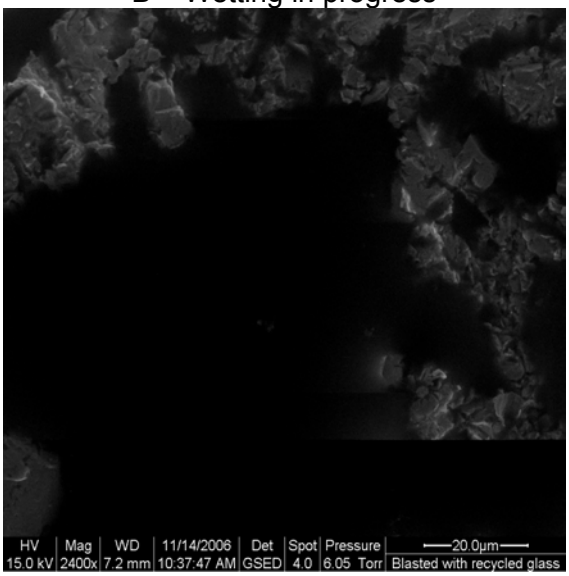
A – Dry surface



B – Wetting in progress



C – Wetting in progress



D – Specimen partly flooded

I4: Wetting characteristics around a particle