PROPERTIES OF GROUND GRANULATED SLAGS IN CEMENT BLENDS

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SUMMARY

Ground granulated slag (GGS) from steelworks at Kwinana, and Port Kembla, N.S. W. have been incorporated into Portland cement blends on a production scale. The GGS has made a considerable impact on the W.A. market but a much smaller impact in N.S. W. due to competition from high quality flyash. Concrete containing a triplex cementitious blend of Portland cement (OPC), ground granulated slag (GGS) and flyash (FA) has been used in N.S. W. since 1966.

This paper presents an assessment of the properties of GGS, from the Port Kembla works, in cement blends.

Slag from one blast furnace at Port Kembla may be granulated either by water or by air (pelletized slag - Slaglite). This is a rare occurrence throughout the world and allows the examination of slags of substantially the same chemical composition but subjected to these vitrifying process alternatives on a production scale. An investigation has shown the hydration reactivity of the two slag types to be not significantly different; however, the pelletized slag was more easily ground. The pelletized slag required an energy input for grinding similar to that of Portland cement clinker.

An examination of the compressive strength of OPC-GGS blends showed no advantage in using GGS ground finer than 350 m/kg (3500 Blaine). 50% OPC-50% GGS blends had similar strength to the OPC alone at 28 days and only slightly reduced strength at 7 days.

Slag cements from Europe are generally reported to have a high resistance to attack by sulphate solutions. However, Australian slags have a higher alumina content and a 50% OPC-50% GGS blend was found to be unstable in a 5% sodium sulphate solution. Other Portland cement and cement fly ash blends were examined and results are

reported. It seems advisable that particular slag cement blends should be examined individually when durability is a concern.

INTRODUCTION

Vitrified blast-furnace slags suitable for the manufacture of slag cement are produced at only two of the four iron and steelmaking works in Australia; Kwinana, Western Australia and Port Kembla, N.S. W. Table 1 shows the production and utilization of slag products for each of the centres (Jones and Murrie, 1980). The development, in the future, of a slag cement capacity at other centres will depend on evidence of a market for this material in the regions adjacent to the works where vitrified slag is being produced. It is this economic factor rather than unsuitability, on any physical or chemical grounds with the slags from the other works, which has restricted slag vitrification to these two works. This is particularly relevant for Newcastle where, at present, plans for construction of a new blast furnace are being considered and the options for slag processing and disposal influence the furnace location and design.

TABLE 1 1979 Annual Production and Utilization of Australian Blast-Furnace Slags (*Steel Furnace Slags)

	Port Kembla		**Newcastle**		**Whyalla**		**Kwinana**
Production (',000 tonnes)	2000	(954)	750	(490)	300	(120)	300
Utilization (',000 tonnes)							
Crushed Slag & Road Base	760		310		70		70
Pelletized Slag	6						
Granulated slag	100						70
Rail Ballast		(70)					
Blast Furnace Feed		(456)		(140)		(84)	
Donations or Land Fill							
Percentage of use for other than Donations or Landfill							

**steel furnace slag shown in brackets in table if produced* From Jones and Murrie (1980)

The vitrified Kwinana slag has made a considerable impact on the Western Australian cement market. The total production of granulated slag (granulated slag is blast-furnace slag which has been vitrified by rapid cooling from the molten state by a water jet to produce a slag with the appearance of a coarse, angular sand), 70,000 t.p.a., is sold to the two local cement companies who manufacture a blended cement comprising 70% Ordinary Portland Cement (OPC) and 30% Ground Granulated Slag (GGS) (Jones and Murrie, 1980). The blended cement produced, 230,000 tonnes, represents 40% of the local market.

The Port Kembla, N.S.W., steel plant, by far the largest in Australia, is located on a narrow coastal strip and faces a considerable environmental problem with slag disposal. The management of the plant has been quite aggressive in trying to increase market options for slag products and has produced vitrified blast-furnace slag* since 1966. Both water granulation, to produce slag sand, and air-water granulation to produce Slaglite" lightweight aggregate pelletized slag, are used at present to produce vitrified slags. However, in spite of being favorably located in relation to the large Sydney market, it has been successful only to the extent of having 20,000 t.p.a. GGS utilized in concrete. This represents only 1.4% of the N.S.W. cementitious material market, comprising 1,400,000 tonnes OPC and 200,000 tonnes flyash (FA) (Kelman, 1979; Munn, 1979). The comparatively small market penetration achieved by GGS reflects the competition from high quality, cheap, abundant, pozzolanic fly ash in N.S.W. Suitable flyash is not available in Western Australia. There is also a cost penalty incurred by the present policy at Port Kembla, where grinding of the slag takes place at the cement plant at BerrIma, 80km from the steel plant and it is then transported a further 80km to the main market in Sydney.

Since the introduction of slag granulation at Port Kembla in 1966, most of the one million cubic meters of concrete used within the works has contained a triplex cementitious blend of 40% OPC and 40% GGS, and 20% FA. A similar blend has also been used within the Newcastle steelworks. The concrete containing this blend has undoubtedly given satisfactory performance; however, penetration into the commercial market has been minimal. This is in contrast with the market penetration achieved by flyash where it has been reported by Munn (1979), that 80% of ready-mixed concrete produced contains flyash where suitable material is available, i.e. in the Newcastle, Sydney, Wollongong region.

In spite of work-supported symposia (Institution of Engineers, Australia, Illawarra Group, 1977; Australasian Institute of Mining and Metallurgy, Illawarra Group, 1979) and several papers outlining the properties of Australian blast-furnace slag cement blends (Ryan, 1969; Ryan, Williams and Munn, 1977; Heaton, 1979) there is no general awareness of the availability of, or the properties of concrete containing this cementitious material.

This paper aims to present the results of some recent research concerning the properties of Port Kembla Works derived aground granulated slag, hopefully to add to present knowledge and to enable concrete users to assess the circumstances which may warrant the consideration of this cement substitute.

INTRODUCTION

The rate of hydraulic reactivity of GGS is slower than for OPC (Ryan, 1969), thus in producing OPC-GGS cement blends the usual practice is to use material of greater fineness to counterbalance the slower reactivity. Granulated blast-furnace slag has also been reported to be more difficult to grind than Portland cement clinker (Ryan, 1969; White, 1979). Thus the need for greater fineness for hydraulic reactivity and increased difficulty in grinding mean that grinding rates for granulated slag become important in plant design and overall economics. For example, if Portland cement clinker and granulated slag are interground, there is tendency for the OPC component to be preferentially ground and to emerge from the grinding process finer than the GGS component (Fulton, 1974). This result is considered less desirable than the reverse where the GGS component is finer. To overcome this problem, most companies produce blended cement grind the OPC and GGS separately before blending with the obvious effect of increased plant complexity and cost.

As reported by Jones and Murrie in 1980, "practice in N.S.W. has been to separately grind OPC and GGS, blending them along with flyash at the ready mixed plant. Swan Portland Cement Limited (W.A.) grinds separately but blends OPC and GGS at the cement plant. It is significant that they grind GGS to a fineness greater than OPC. Cockburn Cement LTD (W.A.) intergrinds the cement and slag to a higher fineness than OPC. Their experience with Western Australian materials indicates no advantage to either method." This means that perhaps the Kwinana granulated slag is not so different from the OPC clinker in ease of grinding or alternatively perhaps the problems of different grinding rates are more conjectural than real.

At Port Kembla two sources of vitrified blast-furnace slag are available. The greater quantity is produced by water granulation and because of its appearance is called slag sand. This material is similar to that produced in Western Australia and this type of vitrification is the most common throughout the world. The other source of vitrified slag at Port Kembla is "Slaglite", a material produced for use as a lightweight concrete aggregate. Slaglite is produced by air and water granulation and because of its appearance is called pelletized slag. This material is manufactured under license from National Slag Company LTD of Canada who developed the process. Pelletized slag is used in Canada to manufacture slag cement and is claimed to require less energy to dry and then grind than does granulated slag (Emery, Hooton and Gupta, 1977). Pelletized slag has recently been introduced to Britain and the Frodingham Cement Co. LTD at Scunthorpe uses it to manufacture a slag marketed as "Cemsave". Cemsave has been used to replace up to 75% OPC in concrete (Bamforth, 1980).

The production at Port Kembla of both granulated slag and pelletized slag is a rare occurrence throughout the world and the research report which follows describes a laboratory investigation which compared the ease of grinding of these two slags and OPC clinker.

EXPERIMENTAL METHOD

Granulated slag and pelletized slag were obtained from the Port Kembla steel works and OPC clinker manufactured by the Adelaide Brighton Cement Co. was obtained from the Kooragang Cement Co. at Newcastle. The chemical compositions of samples of the two slags are shown in Table 2 and of the clinker, designated cement K, in the Appendix. The OPC clinker, as received, was unable to be ground in the laboratory ball mill and had to be first passed through a jaw crusher with maximum opening of 10 mm. The particle size distribution of the original materials and the crushed clinker is shown in Table 3. The clinker was ground alone and, as is normal practice in commercial manufacture, with 3% gypsum.

Table 2 Chemical Analysis of the Slag Samples Tested

	Granulated Slag	Pelletized Slag
CaO	38.4	39.4
SiO2	38.8	35.9
Al2O3	16.8	17.4
17.4MgO	1.65	1.8
K2O1.1.658	0.6	0.5
FeO.6	0.7	1.1
MnO	1.13	0.98
S	0.5	0.56
TiO2	1.9	1.35
Others	0.52	1.01

Table 3 Grading of Slag Samples and Clinker

	Percentage Passing Sieve			
			Clinker	
Sieve Opening (mm)	Pelletized Slag Slaglite	Granulated Slag	As Received	Clinker After Crushing
26.5			68	100
12.7			45	100
9.5			40	97
4.75			33	52
2.36	60	89	29	35
1.18	32	53	23	25
0.60	17	12	15	17
0.30	11	0	9	11
0.15	7		5	5
0.075	4		3	3

The materials were ground in a laboratory ball mill. The mill was rubber lined and had internal dimensions 275 mm long, 240 mm dia. It rotated at 64 rpm and was charged with 25 kg of steel balls varying in diameter from 12 mm to 50 mm in approximately 6 mm intervals. The number of balls at each size was approximately the same. A sample mass for grinding of 4 kg was used in each run. This mass gave a volume of pulp to volume of steel balls of 0.4 which is within the range generally considered desirable for efficient grinding. The current used to drive the mill was measured to enable calculation of grinding energy.

EXPERIMENTAL RESULTS

Results of the grinding trial are shown in Figure 1. Fineness was determined by the air permeability (Blaine) method and the points shown are the mean of two tests. The energy consumed in the laboratory scale ball mill, to reach a fineness of 380 m^2/g was approximately 500 MJ/tonne for OPC clinker. This was more than three times greater than that normally needed in full scale production grinding in a mill where fines draw off and pulp additions are continuous (Mills, 1979). This reflects the inefficiency, when compared with full scale production mills, of the laboratory grinding equipment used.

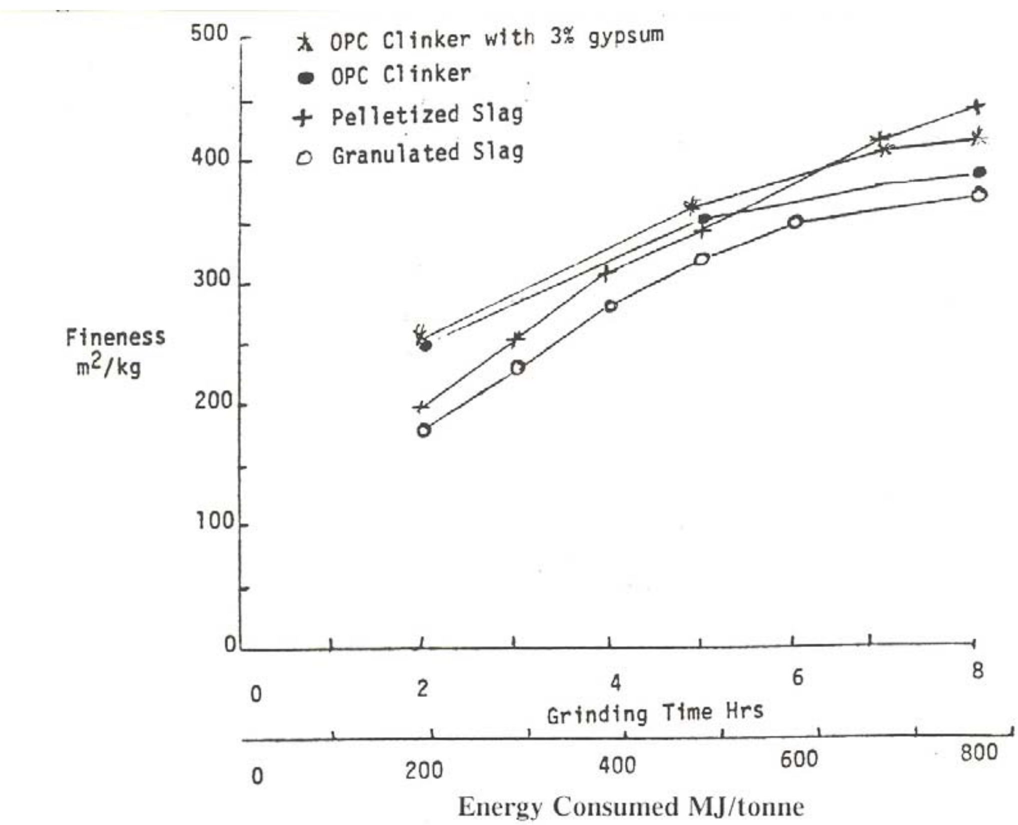


Figure 1. Results of Grinding Tests

DISCUSSION OF RESULTS

The results show that the granulated slag was the hardest to grind. The rate of grinding, with the equipment used, slowed appreciably after a fineness of about 50 m^2/kg was reached and it would have taken an extremely long time to reach a fineness of 400 m^2/kg.

The pelletized slag was easier to grind than the granulated slag and for a fineness greater than 350 m^2/kg was easier to grind than the OPC clinker. The rate of grinding, with the equipment used, did not decrease with fineness to the same extent as with the other materials tested.

While these results are quite interesting as they stand, a further investigation, as described in the next section, revealed no great advantage in grinding the slag to a fineness greater than 350 m^2/kg.

In terms of energy requirements for processing OPC and slag cements, Mills (1979) published the values shown in Table 4 for Canadian pelletized slags. Work done by Blue Circle Southern Cement Company and reported by White (1979) gave the values also shown in Table 4 for Port Kembla GGS. The values reported by White indicate a total energy input for Australian slag cement of approximately 16% of that required for pyroprocessed OPC. If, however, as indicated by this investigation, slag cement of fineness 350 m^2/kg can be produced from pelletized slag with the same grinding energy input as OPC, then the total energy input required to produce slag cement may be as low as 10% of that required for OPC. Furthermore, if the transport component of the slag cement processing values reported by Mills are also removed, as would be appropriate at Port Kembla if grinding was carried out on the plant, and not at Berrima as occurs at present, then the total energy input to produce slag cement could be as low as 5% of that required for OPC. This could have a considerable bearing on the economics of the competition between GGS and flyash in N.S. W. as reported by Heaton (1979).

EFFECT OF FINENESS OF GRINDING ON SLAG CEMENT PROPERTIES

INTRODUCTION

Because blended cements containing GGS have a slower rate of hydraulic reactivity a common practice is to use material of greater fineness to counterbalance the slower reactivity. In view of a substantial dependence of GGS cost on grinding energy, it is considered important to establish the effect of material fineness on OPC-GGS blended cement properties.

In the absence of any known, recent, research published on this topic for Australian slags, it was decided to institute an investigation to assess the effect of fineness of

Table 4 Energy Requirements (MJIT) for Processing Portland Cement and Hydraulic Blast-Furnace Slag

Process	Portland Cement	Blast-Furnace Slag
1. Raw materials processing		
Quarrying and crushing	127	-
Handling	3	54
Transport	-	168
Drying	297	252
Raw Grinding	83	-
2. Pyroprocessing		
Electricity	302	-
Kiln Fuel	5966	-
3. Finish Grinding	144	238 (480)
4. Cooling, conveying and packaging	36	36
5. Totals	6958 (6200)*	748

From Mills, (1979) *(From White, (1979)

grinding on the setting time, compressive strength and durability of OPC-GGS blended cement. The shrinkage of concrete containing OPC and GGS has been reported previously (Heaton, 1979). The assessment of durability is described separately later in this paper. Introduced also into the investigation were the two Port Kembla vitrified slag source variables, granulated slag and pelletized slag.

ASSESSMENT OF GLASS CONTENT

The hydraulic reactivity of slags is primarily governed by three material properties, chemical composition, degree of vitrification or glass content and fineness when ground.

The two slag types, granulated slag and pelletized slag from the Port Kembla works are essentially of the same chemical composition as shown in Table 2.

The glass content of a slag is influenced by how rapidly it is cooled from the molten state. If a slag is allowed to cool slowly then crystallization takes place and these crystals are largely stable and inert when in contact with water. However, rapidly cooled molten slag solidifies as a supercooled liquid or glass. This glassy material, when finely ground and in the presence of a suitable activator m water, will hydrate to form a stable solid product similar to the hydration products of Portland cement. The importance of a distinction between the GGS reaction and a fly ash reaction will be discussed later under the heading durability.

To assess the degree of vitrification or glass content of the granulated and pelletized slags, finely ground samples were examined microscopically under polarized and cross-polarized light. Counts were made of the number of glassy and crystalline particles. These indicated that the granulated slag was approximately 95% glass while the pelletized slag was 92% glass. The degree of vitrification of both slags is obviously high and is therefore satisfactory for production of slag cement.

Where the National Slag LTD pelletizer is used at Dofasco in Hamilton, Canada, to produce pelletized slag for cement, it is operated at a higher drum speed than is used to produce lightweight aggregate (Cotsworth, 1977). It is possible that if this practice was adopted at Port Kembla and some pelletized slag was produced specifically for cement manufacture, then an even higher glass content could be achieved than the 92% measured for the pelletized slag.

TESTING OF THE SLAGS AS CEMENTS

General. Samples of the two vitrified slag types, granulated and pelletized slags, produced in the grinding program were tested to determine their potential as a cement. The samples were available m the fineness range 300m /kg to 450m /kg.

The cements were tested basically in accordance with Australian Standards AS1315-1973 Portland Cement and AS 1317-1972 Blended Cements. AS1317 limits the proportion of GGS in the OPC-GGS cement blend to the range 20 to 65%. Blends of 25% and 50% were chosen for investigation.

Portland Cement. OPC chosen to supplement the GGS in the cement blends was Kooragang Type A which is ground in Newcastle from Adelaide Brighton clinker. The properties of this cement, designated cement K, are listed in the Appendix.

Normal Consistency. In AS1315 and AS1317 the water content of cement mortar used for testing, is given in terms of normal consistency of the cement. This is a measure of the quantity of water required to give a specified consistency and may be equated to a water requirement for workability in concrete.

Tests were carried out in accordance with the requirements of AS1317 for the 25% and 50% GGS blends and it was found that the normal consistency of the blended cement was independent of the slag type, the fineness, or proportion of the slag, and corresponded very closely with the value obtained for the supplementary OPC

Setting Time. The setting time of pastes of mortar at normal consistency were determined in accordance with AS1315 and AS1317.

The time for initial set and final set for all blends was found to be within 15 minutes of the setting time of the supplementary OPC.

Initial set 75 minutes
Final set 150 minutes

This result was contrary to that reported by Ryan (1969), who found a large increase in setting time for blended cements containing 60% GGS and a small increase for cements containing 20% GGS.

COMPRESSIVE STRENGTH

Samples of the cement blends were used to manufacture sand cement mortar cubes. These were manufactured and tested generally in accordance with AS1315 and AS1317 but incorporating the following variations to the standard method:

(i) Local river sand was used instead of the Standard, Leighton Buzzard, sand. The local sand was sieved to obtain that portion which passed the 850 um but was retained on the 600 um sieves. The sand was of regular and uniform shape and similar to the Standard, Leighton Buzzard, sand.

(ii) The mortar in the moulds was compacted with an electrically driven Kango impact hammer fitted with a metal plunger which slid neatly inside the mortar cube moulds. The specimens were compacted in three layers with a total compactive energy calculated to be just in excess of that obtained with the Standard Boehme hammer.

In order to assess the effects of these changes, cubes of OPC were made for comparison with test results obtained by Blue Circle Southern Cement LTD laboratory at Berrima. The results are shown in Table 5.

Table 5 Compressive Strength Ordinary Portland Cement

Time of Testing	Standard Test (MPa)	Modified Test (MPa)
3 days	27.5	27.0
7 days	47.5	47.0
28 days	69.0	57.5

The test results show good agreement at three and seven days but poor agreement at 28 days. The test results had low variability with a standard deviation of 2 MPa and the strength obtained at 28 days was still well above the AS1315 requirement of 45 MPa. In spite of some reservations about the modified method, because of its immediate availability in the test laboratory, it was adopted as a means of comparison for this investigation.

The results of the tests carried out using the two slag types, granulated slag and pelletized slag; in two blends, 75% OPC-25% GGS, 50% OPC-50% GGS; at various fineness levels for the GGS; are shown in Figures 2 and 3.

Figure 2. Compressive Strength of 75% OPC-25% GGS Blend

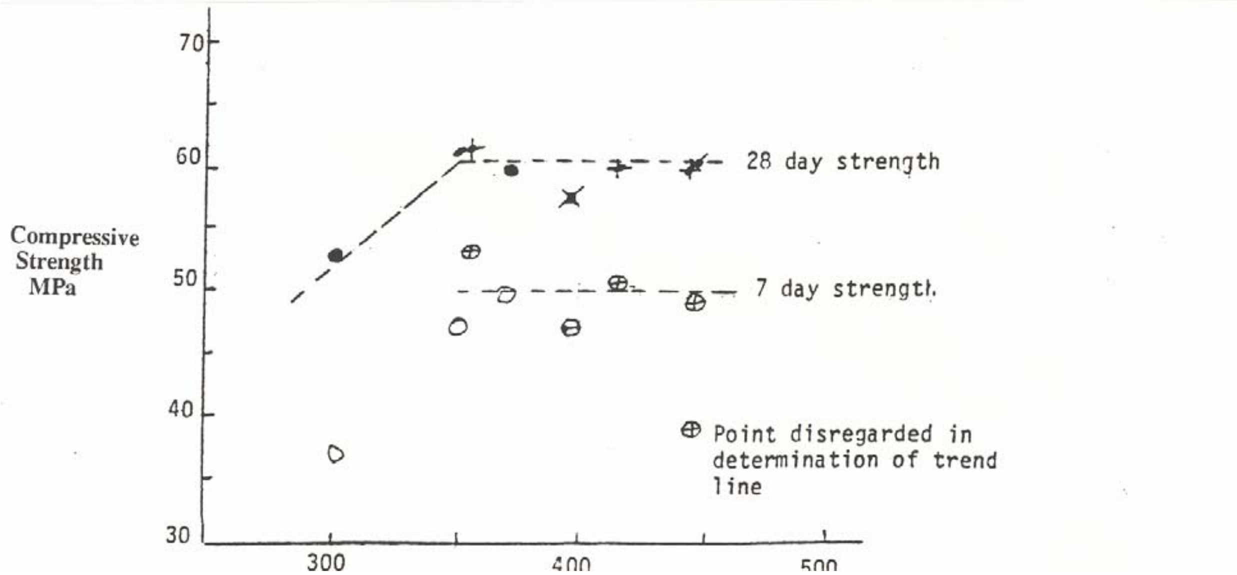
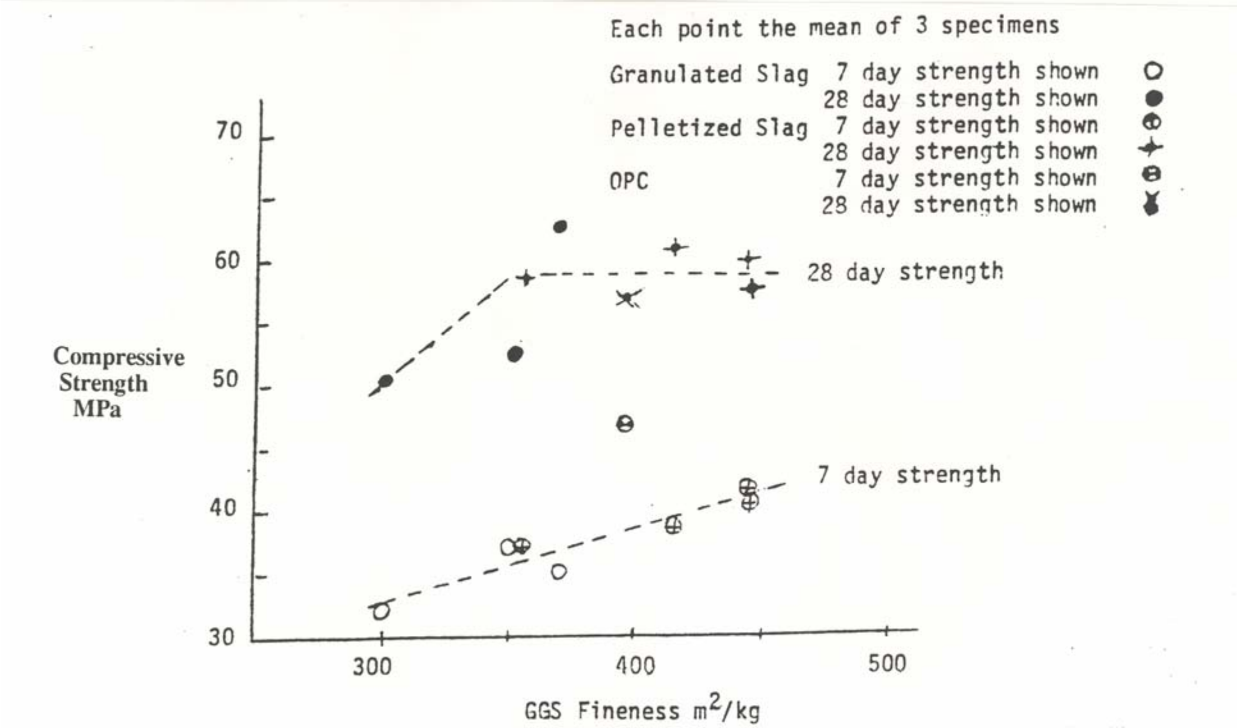


Figure 3. Compressive Strength of 50% OPC-50% GGS Blend



Observations made concerning the compressive strength test results are as follows:

1) There was no significant difference in compressive strength between samples of the same fineness whether derived from granulated slag or from pelletized slag.
2) The strengths of both the OPC-GGS cement blends increased as the GGS fineness was increased from 300 m^2/kg-350 m^2/kg but remained substantially constant when the GGS fineness was further increased from 350 m^2/kg to 450 m^2/kg.
3) The strength achieved by the 75% OPC-25% GGS blend was significantly greater than for the 50% OPC-50% GGS blend at seven days but both had similar strengths at 28 days.
4) The strength achieved by the 75% OPC-25% GGS blend for GGS fineness values greater than 350 m^2/kg was similar to that of the OPC alone at both seven days and 28 days.
5) The strength achieved by the 50% OPC-50% GGS blend for GGS fineness values greater than 350 m^2/kg was similar to that of the OPC alone at 28 days and approximately 85% of the OPC value at seven days.

DURABILITY

The durability of concrete is influenced in many ways by cement, aggregate and additive properties and by mix proportions. In this investigation it was the influence of only the binding cement matrix which was under consideration. Particularly important in this regard was a comparison of cements containing partial replacement by GGS with those containing flyash.

The cementing action of GGS is unlike the reaction which takes place between Portland cement and flyash. Flyash is a pozzolan. A pozzolan is a finely divided silicious material which, though not cementitious itself, combines with lime in the presence of water to form solid calcium silicate hydrates. During the setting of Portland cement-flyash blends, the pozzolanic flyash combines with lime liberated from the hydration of the Portland cement. The hydration of GGS is that of a true cement where an activator, or catalyst, though necessary to trigger the reaction is not consumed in the reaction (Lea, 1970). However as Portland cement is often used as the activator for GGS the confusion with a pozzolanic reaction is understandable

The importance of the distinction between an OPC-GGS hydration and a pozzolanic reaction arises when considering the durability of reinforced concrete. Steel reaction reinforcement is rendered passive against corrosion by a high alkalinity of any moisture present in the pore spaces of the concrete near the reinforcing bars. This high alkalinity is provided by lime liberated from the Portland cement hydration when ever that lime remains uncarbonated. In that the available lime is reduced in a pozzolanic cement, there is a growing awareness of possible problems with the durability of reinforced concrete containing Portland cement-flyash blends (Roper, 1977). This same problem should not occur with OPC-GGS cement blends provided the concrete can be proportioned to give a low level of permeability. Concrete of relatively low permeability can be readily achieved with OPC-FA cement blends. An investigation of this aspect of durability is in progress but results are not yet available.

Sulphate Resistance. The durability aspect which was investigated and has been reported in this paper was concerned with resistance to the attack of sulphate solutions.

It has been generally accepted that cement blends containing blast furnace slags from European steelworks have greater sulphate resistance than ordinary Portland cements (Lea, 1970). Ryan (1969) also reported that concrete specimens containing GGS from the Port Kembla steelworks were more resistant to the attack of a saturated solution of sodium sulphate than were plain concrete specimens.

However, Fulton (1974) has reported that the use of a slag with a high alumina content (18.4%) as was produced in South Africa may result in concrete with poor sulphate resistance. As the slags produced at Port Kembla have a similar high alumina content (17%) it was considered that this warranted investigation.

Sulphate resistance is normally determined by soaking specimens in sodium or magnesium sulphate solutions. The sulphate reacts with free lime to form gypsum which in turn reacts with the tricalcium aluminate to form calcium sulphoaluminates of greater volume than the original hydrates. The resulting expansion causes the hardened concrete to crack and spall. The progress of sulphate attack likely to cause disruptive expansion of concrete specimens, can be monitored by periodic length measurements.

Samples of four specimens each 63mm long by 31.5mm dia. were manufactured of mortar mixes containing three parts sand; one part cement with a water:cement ratio of 0.5. specimens were cured in a fog room at 20°C for 28 days then allowed to dry out under atmospheric conditions for a further 21 days. Stainless steel studs, to enable accurate measurement of length changes, were glued with epoxy resin to the ends of the specimens before they were immersed in a 5% sodium sulphate solution. Length measurements were made at four-week intervals when the specimens were reimmersed in a fresh 5% solution.

The samples of cement used were:

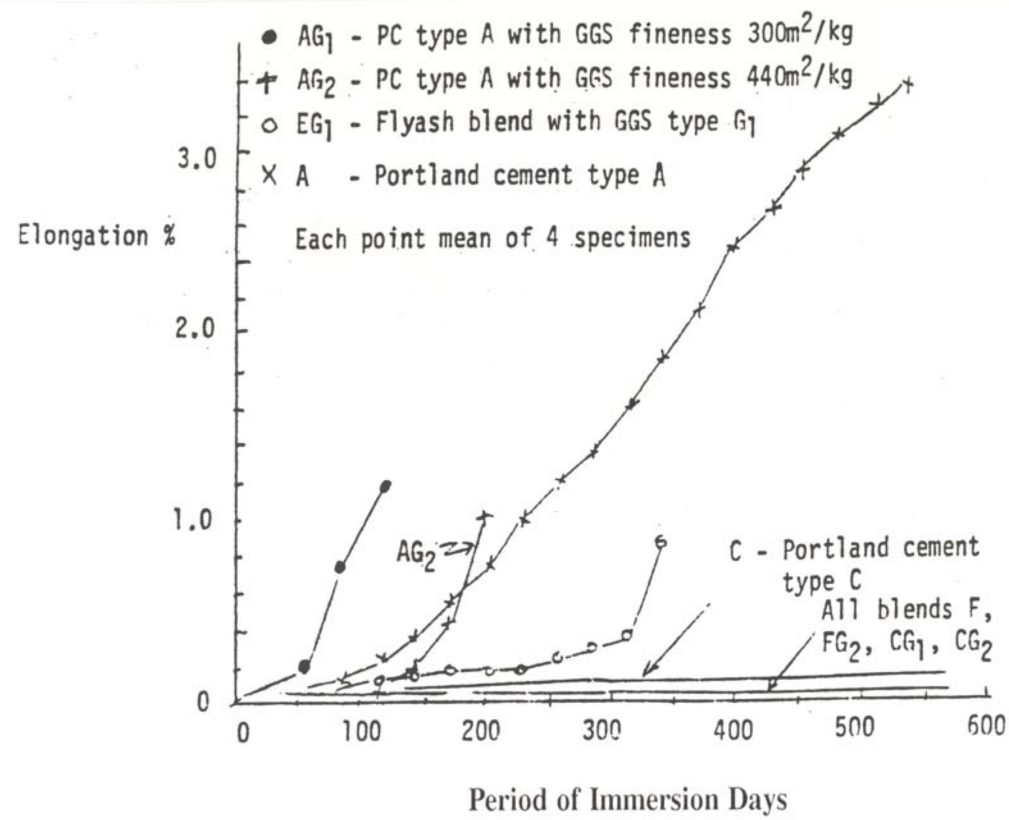
A-Ordinary Portland cement	Type A - C3A content 8%
C-Low heat Portland cement	Type C - C3A content 3.8%
F-Blended cement	Type FA - 28% flyash

AG_1, CG_1, FG_1: Each of the above cements blended with 50% GGS of fineness $300m^2/kg$

AG$_2$, CG$_2$, FG$_2$: Each if the above cements blended with 50% GGS of fineness 440 m^2/kg

Properties of the cement designated A, C and F are shown in the Appendix. Results of the periodic length measurements, expressed as a percentage strain, are shown in Fig.4.

Fig. 4. Elongation of Samples in Sulphate Solution



All specimens initially increased in length due to the saturation process. The early measurements showed a large variation between the four specimens; however, later measurements showed a credible low variability.

The sample AG$_1$ containing Type A Portland cement and the coarsely ground slag, continued to increase in length after initial saturation. All specimens ruptured within 120 days of the first immersion in the solution. Total expansion at rupture averaged 1.25%. This was the least durable sample.

The sample AG$_2$ containing Type A Portland cement and the finely ground slag, did not increase in length Immediately following saturation; however, after approximately 100 days the specimens started to expand rapidly and all broke up at approximately 200 days immersion. Total expansion at rupture was about 1%.

The sample FG_1, containing blended FA cement with the coarsely ground slag showed a continuous small increase in length up to 250 days followed by a rapid expansion and rupture after 350 days immersion. Total expansion at this time was 0.8%.

The sample A, containing Type A ordinary Portland cement alone, showed a continuous medium rate of expansion for a very long period of time before final rupture at approximately 550 days with a total expansion of more than 3.5%.

The sample C, containing Type C Portland cement alone was stable in the sulphate solution showing a continuous low rate of expansion so that following immersion for 550 days total expansion was only 0.15% with no sign of spalling or disruption.

All other samples, including FG_2 containing blended FA cement with the finely ground slag, were stable in the sulphate solution showing negligible expansions following initial saturation and final expansions of less than 0.10% with no sign of spalling or disruption.

The hypothetical tricalcium aluminate, C_3A, content of the sample C, Portland cement Type C, was 3.8% which is less than the 5% maximum required by AS1315 for Type D sulphate resisting Portland cement. Sample C, therefore, meets the requirement for sulphate resisting cement and may be taken as a standard in comparing sulphate resistance. The expansions recorded with the samples CG_1, CG_2 F and FG_2 were all less than the values recorded for sample C and it could therefore be taken that these blends have sulphate resistance equivalent to the standard required for Type D sulphate resisting Portland cement.

The differing results recorded for the two samples FG_1 and FG_2 containing blended cement type FA and the coarsely ground and finely ground slags, indicate that not only chemical compositions, or slag proportion but also slag fineness must be a contributing factor to durability.

Interpretation of these results was difficult as the factors contributing to total expansion or rupture were rather obscure. However, it does seem clear that the partial substitution of Port Kembla derived ground granulated slag for Type A Portland cement does not necessarily produce a cement blend more resistant to sulphate attack. It is recommended, therefore, that proposals to use particular GGS cement blends should be assessed individually.

CONCLUSIONS

The paper has described an investigation which compared the properties of blended cements manufactured from granulated and pelletized blast-furnace slags from the Port Kembla steelworks.

The investigation revealed that pelletized slag was easier to grind than granulated slag and required an energy input for grinding similar to that of Portland cement clinker. The hydration reactivity of the two slag types was found to be not significantly different.

The compressive strength of OPC-GGS cement blends increased as the GGS fineness was increased from 300 m^2/kg to 350 m^2kg but remained substantially constant when the GGS fineness was further increased from 350 m^2/kg to 450 m^2/kg. The strength achieved by a 75% OPC-25% GGS blend was similar to that of the OPC alone at both seven days and 28 days. For a 50% OPC-50% GGS blend the strength was similar to the OPC alone at 28 days and approximately 85% of the OPC value at seven days.

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Mr. R. Dunn, Mr. J. Murrie, Mr. R. Williams, A.I. and S. Pty. LTD, Port Kembla Sulphide Corporation Pty. TD, Newcastle

Mr. C. White, Blue Circle Southern Cement Co. Pty. LTD

Mr. D. Kennard, Mr. R. Elliott, Kooragang Cement Co. Pty. LTD, Mr. D. Hooton, McMaster University, Canada

Mr. R. Cotsworth, National Slag LTD, Canada

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APPENDIX

Properties of Cements Used (Test Results courtesy Berrima Lab. Blue Circle Southern Cement Co.)

	Cement	Type		Designation
Description of Test	K	A	C	F
Loss on Ignition %	1.5	2.1	0.9	2.0
Insoluble Residue %	0.7	0.2	0.2	-
SO_3	2.3	2.3	2.1	2.0
MgO	1.7	1.1	1.2	-
Hypothetical Composition				
C_3S	49	56	30	-
C_2S	25	19	45	-
C_3A	8	8	3.8	-
C_4AF	9	9	16	-
Al_2O_3/Fe_2O_3 ratio	1.7	1.6	0.9	-
Normal Consistency % water	24.5	25	24	29.3
Initial Set minutes	75	90	75	150
Final Set minutes	150	165	150	285
Mortar Compressive Strength				
3 days MPa	27.5	46.5	24.0	34.0
7 days MPa	47.5	49.0	35.0	44.5
28 days MPa	69.0	63.0	69.0	68.0
Fineness Index m^2/kg	395	390	345	-