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EVALUATION OF TURKISH INDUSTRIAL WASTES AS BLASTING ABRASIVES

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Surface preparation is the key factor in determining the success of a protective coating system. Failure to ensure high standards of surface preparation will eventually have a detrimental effect on the life and performance of the coating system applied. Preparation of steel is best achieved by the use of abrasive blast cleaning to remove millscale and rust and provide a suitable surface profile for application of the coating system. Materials from different origins can be used as a blasting medium including coal slag, smelter slag, mineral abrasives, metallic abrasives, and synthetic abrasives.

This paper represents evaluation of Turkish industrial wastes as abrasives in blast cleaning operations. Three different slag samples of two sources were investigated. The samples were prepared by crushing, screening and washing. The chemical composition and physical characteristics of the samples were determined. All the samples were tested on industrial scale.

Test results showed that converter slag meet all the specifications for abrasives and it can be used in blast cleaning operations. However, coal furnace slag and granulated blast furnace slag are not suitable for use as blasting abrasive.

Key words: industrial waste, surface preparation, abrasive, blast cleaning, slag

INTRODUCTION

An essential preliminary to any coating operation is proper surface preparation and its importance cannot be overemphasized. It is believed that of the cost of a coating job, as mush as two-thirds goes for surface preparation and labor (NACE, 2000). There are no coatings which will provide long term protection when applied over a poorly prepared surface.

Abrasive blasting is the most widely used method of surface preparation. It is the process of propelling abrasive particles from a blast machine, using the power of compressed air (Hansel, 2000). Its importance has long been known and several

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researches on blasting pre-treatment have been conducted (Wingen, 1988; Momber and Wong, 2005; Kambham et al., in press; Rosenberg et al., in press) and its effects on adhesiveness of coating systems have been investigated (Amada et al., 1999; Griffiths, 1996; Mellali et al., 1994; Amada et al., 1998; Harris and Beevers, 1999; Çelik et al., 1999; Staia, 2000).

A vital component in successful preparation of surfaces by abrasive blasting is the blasting media (Robinson, 2000). Copper slag, coal slag, garnet, steel grit, and steel shot are common blasting abrasives. Traditionally sand was used, but metallic grit and slag abrasives have replaced it due to the adverse health and environmental effects of silica dust associated with sand. Besides environmental and health concerns, there are numerous considerations in selection of suitable media. While quality and performance of an abrasive is determined by its physical properties and chemical cleanliness, availability and cost mainly determine the economics of abrasives. Although there exists well known blasting abrasives in market, local supply restricts their usage. This situation has led the authors to conduct such a research. The objective of this research is to produce blasting abrasives from Turkish industrial wastes and investigate the usability of produced abrasives in surface preparation technologies.

EXPERIMENTAL

MATERIALS

Three different slag samples of two sources were investigated and tested. A coal furnace slag sample from Çayırhan thermal power plant (Ankara), a granulated blast furnace slag and a converter slag sample from Ereğli Iron and Steel Works.

Coal slag is a coarse, granular, gray colored waste-product that is collected from the bottom of the furnace that burn coal for the generation of steam. It contains white and brownish particles and porous granules of 1.5 cm maximum size. Granulated blast furnace slag is water-quenched, glassy, yellowish, sand-like granules with a top size of about 5-6 mm. Converter slag is the air-cooled steel furnace slag, sometimes called as steel slag, and the sample contains brownish grey vesicular lumps with a top size of about 15-20 cm.

MATERIAL CHARACTERIZATION

Physical characteristics and chemical cleanliness of the materials was evaluated in accordance with Turkish standard TS EN ISO 11126 (2002) which is adopted from ISO standards. Samples were assessed from the aspects of size distribution, apparent density, hardness, moisture content, water soluble contaminants and water-soluble chlorides. Those specifications are determined by the methods described in TS EN ISO 11127 Part 2 to 7 (2002). Chemical composition of the materials was determined by X-ray fluoresce method.

SAMPLE PREPARATION

Since original samples have different physical characteristics, pretreatments of test samples before sizing were performed in different ways. Converter slag sample were first crushed in a jaw crusher to below 3 mm - the maximum allowable size for blasting abrasives - because of its lumpy nature. On the other hand, coal furnace and granulated blast furnace slag samples were air-dried before sizing due to their high moisture content. Samples were sieved for specified sizes, 1.2 mm – 0.3 mm. Oversize materials were re-crushed and undersize materials were rejected.

INDUSTRIAL APPLICATION

Prepared samples were tested in Sedef Shipyard (İstanbul) from performance and quality aspects using industrial scale blasting machine. Blasting conditions are given in Table1. Rusted steel surfaces were selected from the plates of a ship in maintenance. Plates were blasted until all of the samples were consumed and the surfaces were evaluated. In order to assess the surface cleanliness, Turkish standard TS EN ISO 8501-1 (2000) was used. Surface profile pattern of blasted surfaces were evaluated using Rugotest No. 3 surface profile comparator.

Table 1. Blasting conditions during industrial application

Stand-off distance	~ 60 cm
Blasting angle	60-90°
Air Pressure	700 kPa
Nozzle diameter	10 mm

RESULTS AND DISCUSSION

CHEMICAL COMPOSITION

Coal slag is mainly an aluminum silicate material. Chemical analysis of the coal furnace slag sample and Eurogrit coal slag abrasive is given in Table 2.

Table 2. Chemical analysis of coal furnace slag sample and eurogrit coal slag abrasive

Components	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	Na_2O	K_2O	Other	LOI
Eurogrit* (%)	45-52	24-31	3-8	7-11	2-3	0-1	2-5	traces	-
CFS (%)	48.1	10.5	13.7	7.4	6.2	1.6	1.6	0.9	9.6

* source: http://www.eurogrit.nl/temp/uk_us/index.html.

Chemical compositions of two coal slags showed that aluminum content of coal furnace slag is quite lower than that of coal slag abrasive used in industry. However, its calcium and magnesium content is higher compared to Eurogrit coal slag abrasive.

Those differences are possibly due to the petrographical and mineralogical compositions of coal and its associated mineral matter. Chemical analysis of coal furnace slag also reveals that there is almost 10 % loss of ignition, which is possibly the indication of unburned coal.

Results of the chemical analysis of granulated blast furnace slag sample and typical slag composition obtained from National Slag Association (USA) is given in Table 3. Apart from the little variations, granulated blast furnace slag seems to be a typical calcium silicate slag.

Table 3. Chemical analysis of granulated blast furnace slags

Components	FeO	SiO_2	MnO	Al_2O_3	CaO	MgO	S	Other
NSA (%)	0.2-1.6	27-38	0.15-0.76	7-12	34-43	7-15	1.0-1.9	-
GBFS (%)	0.09	36.82	0.56	15.38	40.80	4.91	1.20	0.15

The chemical composition of Turkish converter slag and its counterparts from South Africa (Lieuw Kie Song and Emery, 2001), Taiwan (Li, 1999) and USA (NSA, 2005) is given Table 4. High iron and CaO contents of converter slag sample draw attention. The reason may be originated from higher scrap and lime addition to produce a strongly basic slag. Although most of calcium exists in bound crystalline form with the other constituents, converter slag can also contain free lime.

Table 4. The major components of converter slags

Components	Total Fe (%)	FeO (%)	SiO_2 (%)	MnO (%)	Al_2O_3 (%)	CaO (%)	MgO (%)
Converter Slag (Turkey)	21.87	9.36	9.62	4.66	0.89	49.48	2.39
South Africa	19.2	12.1	12.5	4.8	4.1	36.4	8.9
Taiwan	1-8	5-20	13-16	4-7	0.9-1.7	45-52	4-6
USA	-	24	15	5	5	42	8

STANDARD SPECIFICATIONS

Turkish standard TS EN ISO 11126 evaluates the materials from the aspects of size distribution, apparent density, hardness, moisture content, water soluble contaminants and water-soluble chlorides.

According to this standard, abrasive particles should not be coarser than 3.15 mm and amount of particles finer than 0.2 mm and coarser than 2.8 mm should not be higher than 5 %. Particle size distributions of coal furnace slag and granulated blast furnace slag samples showed that original materials can not be used as an abrasive in blast cleaning without sizing. However, more than 70 % of original coal furnace slag and almost 90 % of original granulated blast furnace slag can be utilized as abrasive after only a proper sizing. On the other hand, lumpy nature of converter slag necessitated a crushing stage before sizing. After successive crushing and sizing it is also seen that more than 90 % of converter slag can be used in blast cleaning operations from the point of size distribution. However, they should meet the other requirement in order to be used in industry.

Measured apparent densities of investigated materials and specifications stated by related standards are given in Table 5.

Table 5. Apparent densities of materials

Material	Coal Furnace Slag	Granulated Blast Furnace Slag	Converter Slag
TS EN ISO 11126 (kg/dm^3)	2.4-2.6	3.0-3.3	-
Sample (kg/dm^3)	2.1	2.4	3.8

As it is seen from Table 5 coal furnace slag and granulated blast furnace slag samples do not meet the specifications. Both of them are below the required values. Lower apparent density of coal furnace slag is attributed to its chemical composition. Low aluminum content and unburned coal possibly reduces its apparent density. As to granulated blast furnace slag, its apparent density is much lower than specified values. This might point out a porous structure possibly due to cooling regime. Converter slag has the highest apparent density among studied materials. It might be due to high iron content in the slag and possibly occur with scrap metal additions during steel production.

Specifications of non-metallic abrasives covered in TS EN ISO 11126 with the investigated slag samples are compared in Table 6.

Table 6. Specifications of Turkish (ISO) standards with investigated slag samples

Specification	TS EN ISO 11126	CFS	GBFS	CS
Hardness (Mohs)	Min. 6	< 6	> 6	> 6
Moisture Content (%)	Max. 0.2	0.03	0.02	0.03
Conductivity (mS/m)	Max. 25	-	15.7	811
Water Soluble Chloride (%)	Max. 0.0025	-	0.0004	0.0013

Hardness of granulated blast furnace slag and converter slag are obviously greater than 6 in Mohs scale. On the other hand, different particles of coal furnace slag sample scratches the glass slide in different levels, therefore the exact hardness value of coal furnace slag is doubtful and it is considered to be low to be used in blast cleaning. Conductivity of coal slag and its water soluble chloride content were not determined because of its failure in industrial application. While converter slag meets most of the criteria, its conductivity value exceeds the maximum allowable limit. This problem may be overcome by thorough washing with river water. Pre-treatment of washing not only removes the water soluble contaminants but may also prevent dusting generated by adhering fines. Granulated blast furnace slag seems to be appropriate to be used as abrasive from standard specification aspects. However, industrial application determines the final decision.

INDUSTRIAL APPLICATION

Industrial application of converter slag showed that the tested sample cleaned the work surface from most of the mill scale, rust, and foreign matter providing “Sa 2” degree of cleanliness. “Sa 2” is considered, in many cases, satisfactory. However, applied pressure should be high enough and enough cleaning time should be given, up to the point of the best achievable cleanliness. The slag sample also provided surface roughness of B N9a on Rugotest No.3, which is sufficient for general purpose blast cleaning operations. It was also noticed that the tested sample did not leave residues on the work surface preventing contamination. Additionally, it appeared to be a low dusting material, which may otherwise hinder the blasting operation. Therefore, the tested sample was accepted to be a promising candidate, especially with some improvements in its physical properties.

The application of granulated blast furnace slag on the work surface revealed some interesting results. At the first look, it seemed to provide “Sa 2½” degree of cleanliness and created brighter, near to white, surface than does the converter slag. However, the appearance of blasted surface was misleading. When the worked surface was viewed with magnification, it was realized that the sample leaved local traces of contamination in the form of white spots. The residues smear the surface and gave an extra brightness and white look. Comparison of the worked surface with the surface profile comparator showed that the sample provides surface roughness between the mid point of B N9 and B N10 on Rugotest No.3, which is suitable for all purpose blast cleaning operations. In addition, it appeared to be a low dusting material and this provided a superior feature to that sample. As a result, although granulated blast furnace slag has a good cleaning performance, it can not be utilized as an abrasive due to left residues on the blasted surface.

Industrial application of coal furnace slag showed that it was not able to clean the surface from mill scale, rust and paint coatings. Visual assessment of surface cleanliness revealed that the tested sample is not applicable in blast cleaning operations. It did not fulfill even the requirements of the “Sa 1” degree of cleanliness which is the lowest degree in blast cleaning. In addition, it was not able to provide the lowest degree of roughness, which is B N6 on Rugotest No.3. Hence it does not meet the surface profile requirement by the industry, which is commonly in the range of B N9a-B N10a.

CONCLUSIONS

The chemical composition and physical characteristics of alternative blasting abrasives were determined in the light of ISO standards and they were tested in industry. Converter slag meets the hardness, moisture content and water soluble chloride criteria of the standards. However, its conductivity value is above the maximum allowable limit. But it is considered to easily be overcome with thorough washing. Industrial application of converter slag showed that it provides “Sa 2” degree of cleanliness and surface roughness of B N9a, which is accepted as satisfactory in many cases for surface preparation of steel works.

Aluminum content of coal furnace slag is quite lower than that of coal slag abrasive used in industry. However, its calcium and magnesium content is higher and it possibly contains unburned coal. Those differences in its chemical composition are considered to be adversely effective in its physical properties, i.e., toughness, density, etc. The coal furnace slag does not meet the most of ISO specifications and it failed during industrial application. Consequently, it can not be used as abrasive in blasting.

Granulated blast furnace slag meets all of the requirements of ISO standards, except for its lower apparent density, which is attributable to its porous structure. Although the granulated blast furnace slag has a good cleaning performance and provides required surface profile it can not be utilized as an abrasive in preparation of the steel since it leaves local traces of contamination in the form of white spots on the worked surface. Converter slag is mainly utilized as pavements, road construction material and railway ballast. In the literature, there is limited information about the utilization of those materials as blasting abrasive. This study showed that converter slag can be a good candidate after a pre-treatment consisting of crushing, sizing and washing as the same requirement for most of the other blasting abrasives. It is also noticed that any material that meets the specifications of standards may not necessarily be utilized as an abrasive. Industrial application determines the final decision.

In this study only degree of surface cleanliness and roughness are studied. Cleaning rate and consumption of blasting abrasives should also be investigated in order to determine their feasibility to be usable in industry.

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Właściwości powierzchniowe są bardzo ważnym parametrem, który determinuje utworzenie efektywnej warstwy ochronnej na powierzchni ciała stałego. Zaistniałe uchybienia w przygotowaniu powierzchni mogą mieć negatywny wpływ na długość czasu funkcjonowania i jakość powstałego pokrycia powierzchniowego. W procesie otrzymywania wyrobów ze stali, istotna rolę odgrywa użycie odpowiedniego ścierniwa w celu usunięcia rdzy i zgarów, co gwarantuje otrzymanie czystej powierzchni, na którą można nałożyć warstwę ochronną. Materiały, o różnych źródłach pochodzenia, można wykorzystać jako ścierniwo. Do tej grupy materiałów można zaliczyć: żużel węglowy, żużel hutniczy, ścierniwo mineralne, ścierniwo metaliczne i ścierniwo syntetyczne.

W pracy przedstawiony został rozwój tureckiej gałęzi przemysłu, która wykorzystuje odpady jako ścierniwo w operacjach czyszczących. Badaniom poddano trzy żużle pochodzące z dwóch miejsc. Otrzymane próby zostały odpowiednio przygotowane przez zmielenie, klasyfikację na sitach i odmycie drobnej frakcji. Określony został skład chemiczny i właściwości fizyczne badanych próbek ścierniwa. Wszystkie trzy ścierniwa były testowane w warunkach przemysłowych. Wyniki otrzymane z tych testów wskazują, że badane ścierniwa można użyć do operacji czyszczenia. Jednak, żużel węglowy i granulowany żużel wielkopiecowy nie były odpowiednim materiałem dla produkcji past polerskich.