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Use of tire derived fuel in clinker burning

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Abstract

The prerequisites for using of tire derived fuel (TDF) as a supplement fuel for the clinker production are stated. Measurements were carried out by using different qualitative analytical techniques such as, X-ray diffraction (XRD), X-ray fluorescence (XRF), optical microscopy in two series of raw mill, clinker and fuel samples with and without the use of TDF. Furthermore, the compressive strength of CEM I-52.5 cement produced was measured. In this specific study 6% of the total fuel used was TDF. It was concluded that no apparent problems occurred from the use of TDF as a supplemental fuel in the clinker burning.

Keywords: Tire derived fuel (TDF); Clinker burning; Cement; Secondary fuel

1. Introduction

The amount of used tires produced in Greece is roughly 2,000,000 per year. With the exclusion of retreated material, 50% of the remaining is disposed of in landfills, 20% is recycled as raw product for shock protection purposes or for the rubber crumb production, and 30% is used in combustion. Landfill disposal which is the most prevailing method, will be drastically reduced in the near future, due to the recent introduction of European Union directives that include significant restrictions on this practice in favor of alternatives oriented toward materials and energy recovery. Furthermore, the disposal of used tires in landfills, stockpiles, or illegal dumping grounds, increases the risk of accidental fires with uncontrolled emissions of potentially harmful compounds [1–3].

The high calorific value of tires (approximately 31,400 kJ/kg) makes TDF an effective supplemental fuel for cement kilns. TDF substitutes coal and/or other fuels in the cement kiln heating process. It is a consistent fuel. Tires are constructed with a narrow range of materials and have low moisture levels. However, TDF cannot exceed 30% of the kiln fuel without adversely altering the chemistry of the cement's hardening process, because of the large quantities of zinc present [4–6].

Eighty-eight percent of the tire is composed of carbon and oxygen, which accounts for its rapid combustion and relatively high calorific value (as mentioned above). Subsequently, when using TDF instead of coal, a kiln operator can reduce coal by 1.25 t for every ton of TDF used [7–10].

The supply of TDF for cement kilns is broken into two general categories: whole and processed. The basic advantages for using whole tires are described as follows: (1) TDF can be obtained at a positive expense (i.e. in Greece, cement plants receive subsidy for burning tires); (2) the feed/weighing system is simplified—simple hooks can be used for weighing and loading the material; and (3) the acquisition process is simplified—whole tires can be picked up from the point of generation and brought directly to the kiln in a covered truck.

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The major difference between whole and processed tires in this process is the calorific value. The less wire, bead and belt, in tire derived fuels, the higher the calorific value [2,5,6,11].

The high temperatures—typically around 1430 °C—and long residence times inherent in the operation of cement kilns, provide a sufficient disposal technique for waste tires with limited emissions. The solid ash constituents derived from tire combustion (i.e., the steel from the tire beads and belts) are incorporated by clinker phases. Normally iron ore is added in the cement operation. Since tires already contain iron from the beads and steel belts, the addition of iron ore can be reduced. Furthermore, the beads and belts contain zinc, approximately 1.40%, and that may contribute negatively to the cement hydration and hardening [2,10,12].

Another point of interest is that tires tend to have a lower percentage of sulfur than most coals do. Sulfur in tires ranges from 1.24% to 1.30% percent by weight. The average coal used in cement manufacturing will contain 1.5% sulfur approximately. Calcium carbonate, the largest single ingredient in cement, is one of the most effective natural sulfur gas scrubbers there is. The presence of calcium carbonate contributes to control sulfur emissions from a cement kiln. Emissions data from a variety of kilns has clearly demonstrated a consistent reduction in sulfur and other emissions with the use of TDF. Since all the components of the tires are either destroyed, combined into the clinker or captured in the air pollution control device, there is no ash to dispose. Finally, the components of the scrap tire, especially heavy metals such as zinc, chromium, once chemically combined into the clinker, are not capable of leaching out. This is comparable to silica not leaching from glass. In short, the cement kilns use 100% of the scrap tire in a completely environmentally sound manner [7,13].

2. Experimental

Samples were taken from the production in two series. In the first the plant used a mixture of coal and pet-coke as fuel. In the second it used coal, pet-coke and TDF as fuel. In the specific plant, 88% of the total fuel is used in the main burner and 12% in the precalciner. In the first series, pet-coke was used in the main burner and coal in the precalciner, while in the second, half of the coal used was substituted by the same quantity of TDF. The substitution took place only in the precalciner and 6% of the fuel used was TDF. Samples were collected from the following positions:

- The kiln outlet;
- The spray tower;
- The electrostatic filters;
- The fourth cyclone stage;
- The kiln inlet.

The analytical techniques used for the chemical and mineralogical characterizations of these samples were the following:

- X-ray analysis (XRF, XRD) using Siemens XRD D5000.
- Optical microscopy using Nikon Optiphot for reflected light.
- Wet chemical analysis of alkalis, chlorides, sulphates, zinc and chromium [14].

Furthermore there has been a determination of physicochemical properties of cement (CEM I-52.5) produced by clinker with and without TDF [15].

Fuel chemical analysis was performed in the cements' company research laboratory for all three different types of fuel.

3. Results and discussion

Typical analysis of the most commonly used fuel in the clinker burning is shown in Table 1. This table demonstrates why it is safe to use tires as a secondary fuel in the clinker burning. It is obvious that the values of the most important parameters—such as quantities of sulfur, nitrogen, carbon, hydrogen and of course its heating value—in a fuel that it is used for the clinker burning are similar for the most commonly used fuels and TDF, and that supports the view that TDF is an effective fuel for the clinker burning.

In order to evaluate TDF implementation on the clinker production process, it is necessary to measure the volatile content—alkalis, chlorides and sulphates—in different stages of the process. The main problem that arises from the use of different fuels in the clinker burning, is the formation of rings in the kiln caused by salts—such as KCl, K_2SO_4, Na_2SO_4, Ca_2SO_4 etc.—that are formed by the volatiles. This is also known as the *cyclic phenomena*, and the amounts of volatiles and especially sulfur, contained in the fuels, have a direct effect on these phenomena. In this case, blockage in the kiln

Table 1
Comparative typical analysis of fuels

Analysis	Pet-coke	Coal	TDF
Volatile (%)	13.0	36.8	72
Ash (%)	7.1	14	7
Carbon (%)	82.6	80.6	84
Hydrogen (%)	3.4	4.6	5
Sulfur (%)	4.9	0.7	2
Nitrogen (%)	1.75	0.3	1.75
Lower heating value (kJ/kg)	32,480	27,430	31,400

seems to be the most harmful outcome since kiln shut down follows. This stoppage of the cement kiln is very costly.

Quantitative analytical results of the samples taken during the two periods are given in Tables 2 and 3. From the comparison of Tables 2 and 3 it is shown that the values of the alkalis, chlorides and sulphates are in fact very similar in the case when TDF was used as a secondary fuel and in the case that TDF was not used at all.

Another factor that is studied is the amount of zinc in the produced clinker. This is examined because of the direct effect that the amount of zinc in clinker has in the hardening process of the cement. Small amounts of zinc (0.01–0.2%) have been reported to increase the reactivity of C_3A and lead to possible setting problems without altering other hydraulic properties [16]. TDF contains large amounts of zinc coming from tires' steel belts and for that reason it should be used cautiously.

The amount of zinc, in the clinkers is shown in Tables 2 and 3. The results indicate that there is no problem deriving from its concentration. However, it will definitely be a problem if greater amounts of tires were used in the clinker burning.

The last factor that is measured is the amount of total chromium in the produced clinker. The European Union and the rest of the advanced world have set limits for the amount of water soluble Cr in the clinker. Directive 2003/53/EC of 18 June 2003 prohibit, among other requirements, the marketing and use of cement and cement-containing preparations which, when hydrated, contain more than 0.0002% of water-soluble hexavalent chromium, determined as percentage by mass of dry cement. This legislation is intended to minimize the occurrence of chromate-related allergic contact dermatitis arising from the use of cement or cement-containing preparations [17]. The amount of total chromium, in the clinkers is shown in Tables 2 and 3. The amount of total chromium when TDF is used in clinker burning is the same with the amount of total chromium when TDF is not used. Thus the amount of hexavalent chromium will be the same since the production process is the same. That means that problems concerning the amount of chromium deriving from the use of TDF are not expected.

The mineralogical composition of the clinker samples was examined by means of XRD-analysis. XRD-patterns are presented in Fig. 1. The main compounds observed were monoclini C_3S and C_2S, brownmillerite $Ca_2(Al,Fe)_2O_5$ and $Ca_2Fe_{1.52}Al_{0.48}O_5$, $Ca_3Al_2O_6$. Finally the presence of portlandite $Ca(OH)_2$, and aphthitalite $(K,Na)_2SO_4$ was detected in both cases. Portlandite formations are likely attribute to free lime hydration. XRD analysis shows that the compounds are formed in a similar way. There is no apparent difference between the two XRD patterns indicating that the use of TDF in the clinker burning does not create any undesirable compounds.

Clinker microstructure was examined by optical microscopy in polished sections. The use of TDF as a supplement fuel in the clinker burning did not seem to affect its microstructure and the formation of its characteristic mineralogical phases (Fig. 2(a) and (b)). The alite crystals appeared to be well formed and slightly decomposed probably due to differences in burning/cooling conditions. C_3S was slightly decomposed not due to the use of TDF but for other reasons. The belite phase appeared as fine crystals, in low proportion. Finally, the liquid phase occurred as fine crystals, uniformly distributed. As it is obvious the burning with the use of TDF was as good as the one without the use of TDF.

In order to conclude this study, CEM I-52.5 cement was produced, in semi-industrial scale according to EN 197-1, and compressive strength was measured

Table 2
Chemical analyses of the samples without TDF (LOI free)

Samples	Loss on ignition (%)	K_2O (%)	Na_2O (%)	Cl^- (%)	SO_3 (%)	Soluble Zn (%)	Total Zn (%)	Total Cr (%)
Clinker	–	0.60	0.20	0.01	0.72	0.01×10^{-3}	0.04	7×10^{-3}
Cooling tower dust	36.55	0.99	0.27	0.14	1.40	–	–	–
Filter dust	36.18	1.07	0.18	0.90	3.01	–	–	–
Fourth cyclone dust	22.73	1.76	0.21	0.92	3.62	–	–	–
Kiln inlet dust	36.58	0.55	0.20	0.01	0.16	–	0.04	–

Table 3
Chemical analyses of the samples with TDF (LOI free)

Samples	Loss on ignition (%)	K_2O (%)	Na_2O (%)	Cl^- (%)	SO_3 (%)	Soluble Zn (%)	Total Zn (%)	Total Cr (%)
Clinker	–	0.59	0.20	0.01	1.13	0.01×10^{-3}	0.08	7×10^{-3}
Cooling tower dust	36.99	1.11	0.15	0.48	0.84	–	–	–
Filter dust	36.32	1.12	0.18	0.39	2.99	–	–	–
Fourth cyclone dust	16.46	1.75	0.21	0.91	4.07	–	–	–
Kiln inlet dust	35.65	0.55	0.20	0.01	0.16	–	0.08	–

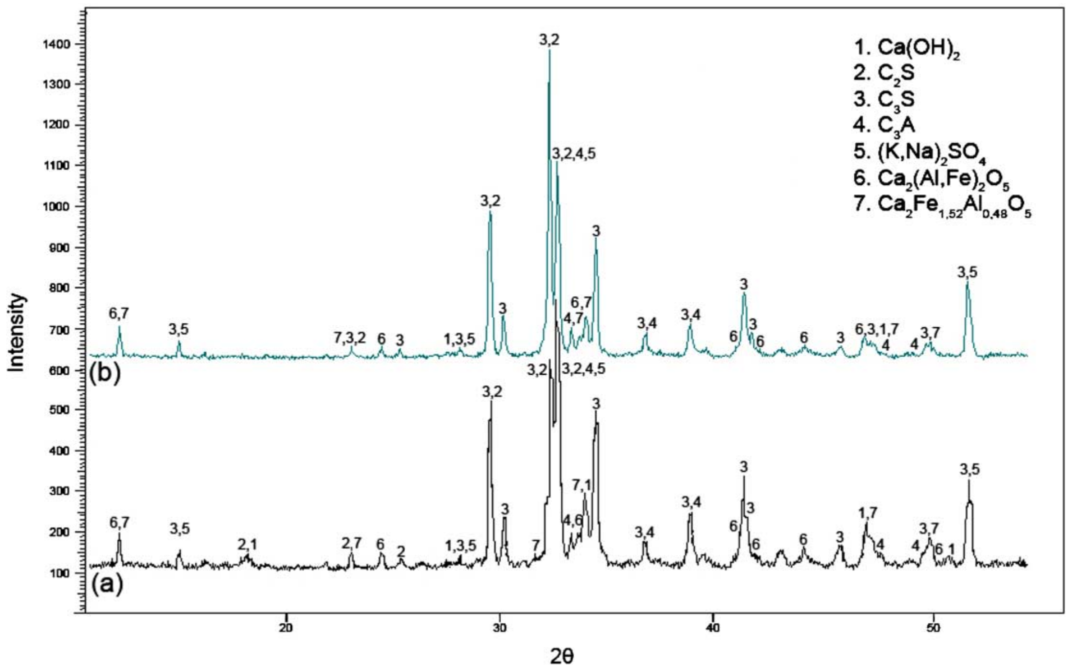

Fig. 1. X-ray diffraction of clinker samples without TDF (a) and with TDF (b).

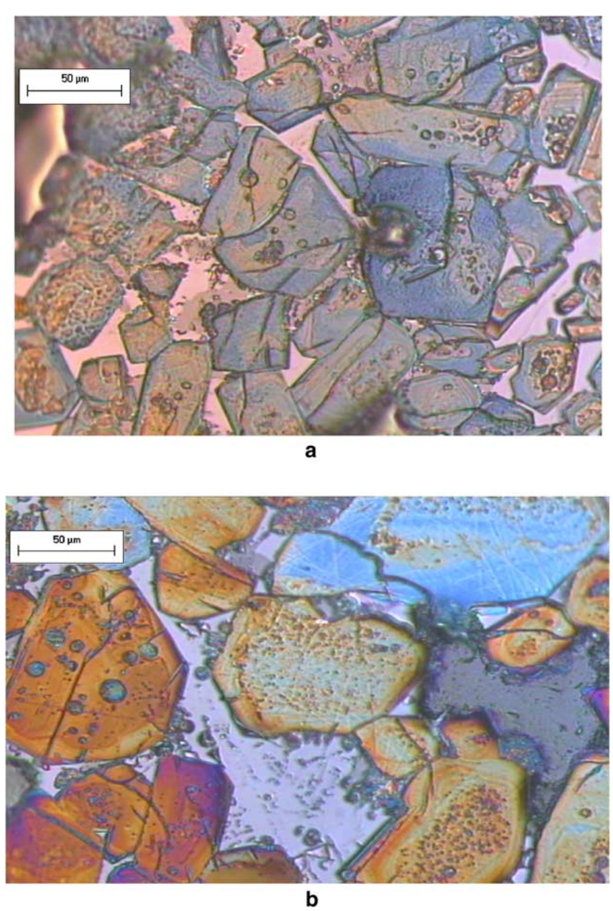

Fig. 2. Microstructure of clinker sample without TDF (a) and with TDF (b).

Table 4
Cement properties and measurements of compressive strength for CEM I-52.5 cement

Cement properties	Without TDF (MPa)	With TDF (MPa)
Composition, %	95.5 Clinker	96.5 Clinker
	4.5 Gypsum	3.5 Gypsum
Blaine,	3860	3680
IST, min	180	220
FST, min	115	170
H_2O, %	25.6	27.4
Age		
1 day	20	17.5
2 days	29.5	30.4
7 days	43	46.7
28 days	62	62.3

(EN 196-1). The results of this analysis and cement properties are shown in Table 4. The measurements of compressive strengths when TDF was used in the clinker burning are similar to those when TDF was not used. As expected due to zinc content there is an increase in setting time of cement, while the increase in cement water demand can be attributed also to grain size distribution.

4. Conclusions

The conclusions derived from the present research work are as follows:

- The industrial process of sintering in rotary kilns, involved in cement manufacture, affords the possibility of using TDF as alternative fuels in substitution of conventional fuels. This entails environmental advantages such as complete destruction of the organic compounds found in the residues due to high temperatures and long periods of time in an oxygen-rich atmosphere.

- The use of TDF as an alternative fuel is cost effective. Whole scrap tires can be obtained by an operating facility at low cost. The use of scrap tires reduces the tonnage of the coal used, and consequently lowers the cost associated with the acquisition of coal. Finally, the steel component of a tire can substitute for iron, which reduces the cost of iron acquisition.
- In this research 6% of the total fuel used was TDF and the results were very promising. Differences in the final product quality were observed only in cement setting time and water demand.

References

[1] Conference, Cement industry and the management of specialized and hazardous wastes, Athens 12 October 2000, Hotel Grande Bretagne, Constitution Square, Technical Chamber of Athens.

[2] U.S. Scrap Tire Markets 2001, Rubber Manufacturers Association.

[3] California Integrated Waste Management Board Publications No: 540-99-006, California waste tire program evaluation and recommendations.

[4] California Integrated Waste Management Board Publications No: 432-96-029, Effects of waste tire facilities, and waste tire projects on the environment.

[5] The use of scrap tires in the cement rotary kilns, Scrap Tire Management Council.

[6] The use of industrial waste as alternative fuels in the cement industry, DIS-1289-97-ES.

[7] Giugliano M, Cernuschi S, Ghezzi U, Grosso M. Experimental evaluation of waste tires utilization in cement kilns. J Air Waste Manage Associat 1995(12):1405. 1405-14 D 1999.

[8] Environmental protection Act 1990, Environment agency, Substitute fuels protocol for use on cement and lime kilns.

[9] Pollution Prevention and Control Act 1999, Environment Agency, Tyres Protocol A supplementary note to Substitute Fuels Protocol, November 2001.

[10] Constans D, Gossman D. Tire derived fuel use in cement kilns. GCI tech notes, Vol. 3, No. 9. A Gossman Consulting, Inc. Publication; 1997.

[11] California Integrated Waste Management Board Publications No: 400-94-012, California's waste tire challenge.

[12] California Integrated Waste Management Board Publications No: 212-97-024, Shredded tires as alternative daily cover at municipal solid waste landfills.

[13] California Integrated Waste Management Board Publications No: 401-93-001, Tires as a fuel supplement: feasibility study.

[14] EN196-21, EN196-2, Methods of testing cement, 2000.

[15] EN196-1, Methods of testing cement. Determination of compressive strength.

[16] Hewlett PC, Lea's chemistry of cement and concrete, 4th ed., 1998.

[17] prEN 196-10 Methods of testing cement-Part 10: determination of the water-soluble chromium (VI) content of cement, 2005.