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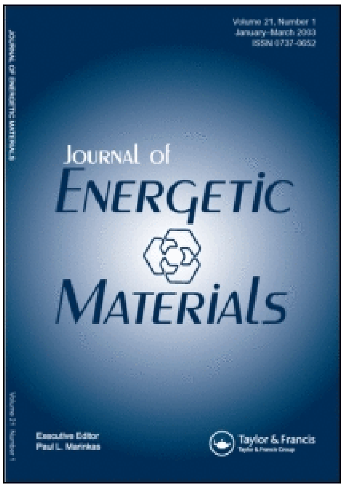

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FACTORS THAT AFFECT THE IMPACT SENSITIVENESS OF AMMONIUM NITRATE - FUEL OIL (ANFO) EXPLOSIVES CONTAINING ALUMINIUM

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Abstract

We report the results of a study to investigate the effect of aluminium on the impact sensitiveness of a range of Ammonium Nitrate-Fuel Oil (ANFO) mixtures.

The data obtained indicate that the impact sensitiveness of these mixtures depends on the quantity and type of aluminium, and on the

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ratio of ammonium nitrate to fuel oil. The magnitude of the dependences is relatively small, however, and all the aluminium-ANFO mixtures examined can be classed as "comparatively insensitive". We have also shown that the sensitiveness of such mixtures to impact can increase if they contain small quantities of rust or grit as a contaminant.

INTRODUCTION

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Ammonium Nitrate - Fuel Oil (ANFO) mixtures are often used in commercial blasting as they provide a relatively cheap, general purpose explosive. As an example of the extent of use, an analysis[1] of supply trends for different types of explosives in the USA has indicated that ANFO accounted for 14% of the market share in 1991.

Sensitiveness tests have been applied to many explosives, often as part of an assessment of the hazards in transport[2], and some data have been published for ANFO mixtures.

Sayce[3] has reported sensitiveness tests carried out on ammonium nitrate with various additives including aluminium, diesel oil and woodmeal. Although the impact test apparatus was not the same as in this study since a 440 g drop weight was used, the tests indicated that ANFO mixtures gave only a small percentage of fires from a drop height of 183 cm. Mallet friction test results[3] showed that ANFO and aluminium-ANFO could only be ignited occasionally by relatively high stimulus levels.

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In general agreement with this, Watson and co-workers[4] have noted that "the use of powdered or grained aluminium in ANFO does not adversely affect the sensitivity except possibly to increase its sensitivity to friction", whereas Cook[5], based on determinations of critical diameter and minimum booster required to ensure consistent performance, has stated that "aluminised ANFO has a high precariousness" i.e. high susceptibility to accidental initiation (detonation).

ANFO and other similar AN mixtures are permitted to be manufactured at specific sites in the UK under the terms of a licence issued under an Exemption Order[6] after an assessment has been made of the proposed ingredients and method of mixing of the explosive.

In recent years there has been a tendency to incorporate aluminium in the ANFO mix in order to produce an explosive (Al-ANFO) with better blast characteristics.

In order to provide the UK Explosives Inspectorate with technical information to assist with the assessment of such aluminised mixes, an investigation was recently undertaken to determine whether the

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addition of different quantities of aluminium to ANFO causes any significant increase in the sensitiveness of the resulting mixtures.

Tests were also undertaken with both Al-ANFO and ANFO contaminated with rust and grit, two contaminants which could occur at mixing sites.

Although the mixing processes do expose ANFOs to frictional forces, the useful information that could be gained from standard friction test methods was extremely limited since initial test work indicated that none of the results were on-scale. The experimental emphasis therefore concentrated on impact testing but, because of the relatively low sensitiveness of most of the mixtures, it was necessary to amend standard test procedures in order to enable numerical results to be obtained.

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EXPERIMENTAL

Test Materials

A limited range of samples used in the preparation of industrial Al-ANFO was obtained from a quarry site, and additional quantities of these materials were purchased to enable the laboratory formulation of mixtures.

Aluminium 36/120 mesh (North Derbyshire Metal Products Ltd) was used in preparing the site-mixed material. Samples of this size range and of sizes 20/36 mesh and 240/D, where D = dust, were therefore obtained for the formulation of test samples. In relation to particle size, the designation 36/120, for example, refers to aluminium that passed a 36 mesh sieve but was retained on a 120 mesh sieve.

Al-ANFO was made in the laboratory using aluminium with particle sizes in the three ranges specified above, together with Betapril, the grade of AN being used by some parts of industry. Mixtures of ANFO were made using ICI Anopril. The fuel used was vehicle-grade diesel.

Primarily, the mixtures were made to reflect the variations in the proportions of components likely to be found in industry. However, formulations with a wider variation of ingredients were included to obtain information on the dependence of sensitiveness on certain specific parameters, and also to represent incompletely mixed or incorrectly proportioned mixtures.

Since Turner[7] has suggested that, in circumstances where there is an excess of oil in the ANFO mixture, the additional oil may drain off and then act as a diluent, the majority of the studies concentrated on ANFO mixtures with relatively low fuel contents.

Samples were made up using all the constituents, mixed as thoroughly as possible, and then ground to pass an 850 μm sieve.

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This became progressively more difficult as the fuel content increased and when sieving of the final mixture was impractical, the mixing process was changed and the components were sieved prior to mixing. For some mixtures, check tests were carried out using both mixing methods in order to determine whether changing the mixing procedure affected the results. There was some variation in these results but it was significantly less than the variations generally found in repeat tests with a given sample produced using one mixing technique.

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In experiments to examine the effect of the presence of gritty contaminants on sensitiveness, the impurities (sharp sand or ground, dried rust) were not sieved but were added as a 2% ingredient to the previously sieved mixtures.

A series of experiments was done with mixtures made up of 4% Al, 94% AN, 2% FO in which the grade of Al was varied by using the three size ranges of 20/36, 36/120 and 240/D. A minimum of 2 experiments was done with each mix.

Test Methods

The Rotter Impact apparatus[2, 8] and the BAM Fallhammer[2] were used to evaluate the impact sensitiveness of the mixtures. Both used drop weights of mass 5 kg.

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Normal Rotter testing uses a Bruceton procedure, which gives results in the form of a Figure of Insensitiveness (F of I). However, since many of the samples gave some no-fire results when using the maximum drop height of 282 cm, the standard procedure could not be used. Excessive damage occurred to consumable components of the apparatus when using this drop height; tests were therefore done using a drop height of 237 cm and the results quoted, in a non-standard manner, as the percentage of fires observed in a series of 50 drops.

Although impact experiments were more easily done than friction tests, there were still experimental difficulties. Because the diesel dampened the samples, it was not easy to ensure that the exact amount was in the extraction scoop or that it was emptied completely. Also, although each sample was made up carefully and mixed until it appeared even, because only a small proportion was selected for test, the composition of the material could have varied within a particular test series.

The assignment of a fire in the Rotter test is based primarily on the production of 1 ml or more of gas. However, because residual material was frequently left on the anvil or in the cap and the production of gas was often accompanied by the evolution of smoke, the SCC Manual[8] criterion of a maximum final manometer reading of $\geq$ 1 ml to designate an ignition was modified for this study. A maximum displacement of the manometer of $\geq$ 1 ml, irrespective of the

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production of smoke, was used to define a fire. 50 drops from 237 cm on samples of inert material (common salt) mixed with diesel indicated the production of between 0.5 and 0.9 ml of gas, which was in keeping with this definition.

During Rotter testing from a height of 237 cm, the anvils still had to be changed frequently because they exhibited deformation. In some initial tests it was noted that a fire could occur when the brass cap became a tight fit on the distorted anvil; therefore, the anvil was always replaced when a tightened fit was observed.

The BAM Fallhammer was the only sensitiveness test apparatus that could give an assessment of both the ANFO and Al-ANFO mixtures using standard procedures and it was used to examine the impact sensitiveness of samples that were contaminated by grit or rust.

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RESULTS

Table 1 lists the results of Rotter tests on Al-ANFO mixtures, while

TABLE 1 Rotter Impact Test Results For Aluminised ANFO

SAMPLE [a]	% FIRES IN 50 DROPS FROM 237 cm
Al-ANFO 4:94:2	40
Al-ANFO 4:94:2	14
Al-ANFO 4:94:2[b]	18
Al-ANFO 4:94:2[b]	22
Al-ANFO 4:94:2[b]	16
Al-ANFO 4:94:2[c]	30
Al-ANFO 4:94:2[c]	28
Al-ANFO 4:90:6	12
Al-ANFO 4:95:1	34
Al-ANFO 10:88:2	56
Al-ANFO 25:73:2	72
Al-ANFO 30:68:2	44
Al-ANFO 40:58:2	48

[a] AN was Betapril, unless otherwise specified; Al was grade 6/120, unless otherwise specified

[b] Al 240/D grade

[c] Al 20/36 grade

Table 2 gives the results of equivalent tests on ANFO mixtures with different proportions of constituents.

TABLE 2 Rotter Impact Test Results for ANFO

SAMPLE (AN : FO)	% FIRES IN 50 DROPS FROM 237 cm
75 : 25	100
80 : 20	100
88 : 12	82, 74
90 : 10	72, 82, 52
91 : 9	16
92 : 8	32
93 : 7	26
94 : 6	16, 18
95 : 5	4, 12
96 : 4	16, 16, 18, 8
97 : 3	12
98 : 2	16
99 : 1	6

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BAM Fallhammer data obtained with mixtures incorporating small quantities of rust or grit contamination are presented in Table 3.

TABLE 3 BAM Fallhammer Test Results

SAMPLE	LIE (J)
ANFO 94:6	35
Al-ANFO 4:94:2	40
ANFO 94:6 + sand	15
Al-ANFO 4:94:2 + sand	25
ANFO 94:6 + rust	15
Al-ANFO 4:94:2 + rust	15

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DISCUSSION

Figure 1 illustrates the dependence of the percentage of fires in 50 drops from 237 cm in the Rotter test on the proportion of 36/120 aluminium in Al-ANFO mixtures with a constant fuel oil content of 2%. The graph indicates that the sensitiveness of Al-ANFO mixtures passes through a maximum for compositions containing ca. 20 - 25% Al.

Previously published results[9] for binary mixtures of titanium and blackpowder have shown that this pyrotechnic composition exhibits a maximum in the dependence of friction sensitiveness on the proportion of metal for mixtures containing ca. 25% titanium. The form of the dependence is similar to that observed in the present work on Al-ANFO and may indicate that a common mechanism operates for the effect of some metal ingredients on the mechanical sensitiveness of certain energetic mixes.

The existence of a maximum in the impact (or friction) sensitiveness for mixtures containing metallic ingredients may reflect the balance between enhanced reactivity caused by the incorporation of particulate metallic material (as also reported for grit and rust[10, 11, 12]) and the heat

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sink effect of a material of high thermal conductivity when present in concentrations greater than 20 - 25%.

Using the data in Table 1, the dependence of Rotter impact sensitiveness results on the relative proportions of AN and fuel oil was examined for mixtures in which the quantity of 36/120 grade Al was maintained constant at 4%. The regression line in Figure 2 indicates that the percentage fires obtained in 50 drops from 237 cm increases as the % of AN increases. There are insufficient results, however, to accurately define the dependence and it is possible that the creation of the optimum fuel-oxidiser mix with 4% Al, 94% AN and 2% FO may be reflected in the relative sensitiveness of mixtures with AN close to 94%

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The dependence of impact sensitiveness on the percentage of AN for mixtures containing Al, Figure 2, appears to be of a different form to that observed in the absence of Al, Figure 3, although the lack of an extensive set of data for the aluminised mixes makes a direct comparison difficult since the data points have a scatter similar to that found for ANFO with AN > 90%.

The regression line in Figure 4 indicates that the impact sensitiveness of Al-ANFO mixtures is dependent on aluminium size over the range 20/36 to 240/D grade aluminium. Whereas fine particles (because of their greater surface area) generally confer reactivity[13], this is not demonstrated by ANFO mixtures incorporating aluminium of the particle sizes examined in this study.

Values for the Limiting Impact Energy (LIE) of mixtures of ANFO and Al-ANFO containing rust and sand obtained using the BAM Impact Test are illustrated in Figure 5 and indicate that both ANFO and Al-ANFO are sensitised by incorporating ca. 2% of sand or rust in the mix. Figure 5 also shows the aluminised mixtures can be less sensitive than ANFO.

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The present study has indicated that the outcome of tests with ANFO mixtures using the Rotter apparatus needs to be carefully assessed. Some drops on mixtures containing high levels of diesel produced less than 1 ml of gas but indicated the production of smoke when the sample housing was opened. The SCC Manual[8] states that the evidence provided by smoke must be carefully considered as the operator could be detecting vapour fumes. In the case of certain ANFO mixtures, smoke may result from reaction of the diesel under compression: the blank runs with common salt/diesel confirmed this.

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CONCLUSIONS

Although there is the potential for mechanical forces to arise during processing of Al-ANFO and ANFO mixtures, our tests have indicated that the mixtures are relatively insensitive to impact stimuli.

For ANFO, the increase in the number of fires observed for mixtures containing high levels of fuel oil may be attributable to detection of a reaction of the fuel and not specifically due to its combination with ammonium nitrate. Analysis of the smoke/gas evolved from such events could give information on the reaction involved.

The addition of aluminium to ANFO mixtures does not cause a major change in their impact sensitiveness (when assessed by small scale test methods) although certain trends and effects have been identified. The magnitudes of the reported dependences are relatively small and in all cases the Al-ANFO mixtures would be classed as "comparatively insensitive" using the SCC definition[8].

Since production facilities may be in harsh environments there is the possibility that contaminants could be unintentionally incorporated into mixes. Limited experiments undertaken with the addition of sand or rust to ANFO and Al-ANFO have indicated a small, but not significant, increase in the impact sensitiveness as measured by the BAM Fallhammer.

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Current small-scale impact sensitiveness tests apply only a single impact to the sample, and the methods may not accurately reproduce all situations that could arise in practice for the mixing of Al-ANFO and ANFO. Nevertheless, our work has shown that some impact tests can be used to yield numerical data which give an indication of the responses of ANFO type materials to impact stimuli and provide a means of ranking with other materials.

There is evidence to suggest that impact forces may not present the same hazard in industrial processes as frictional stimuli[14]. However, the deficiencies of current friction tests when applied to relatively insensitive materials have been highlighted in the current study, and the types of processes involved in automated mixing may require a modified friction test to account for the repeated application of forces to a material. Additionally, it may be necessary to incorporate the ability to undertake assessments at temperatures above ambient. Research is currently being undertaken[15, 16] in this area.

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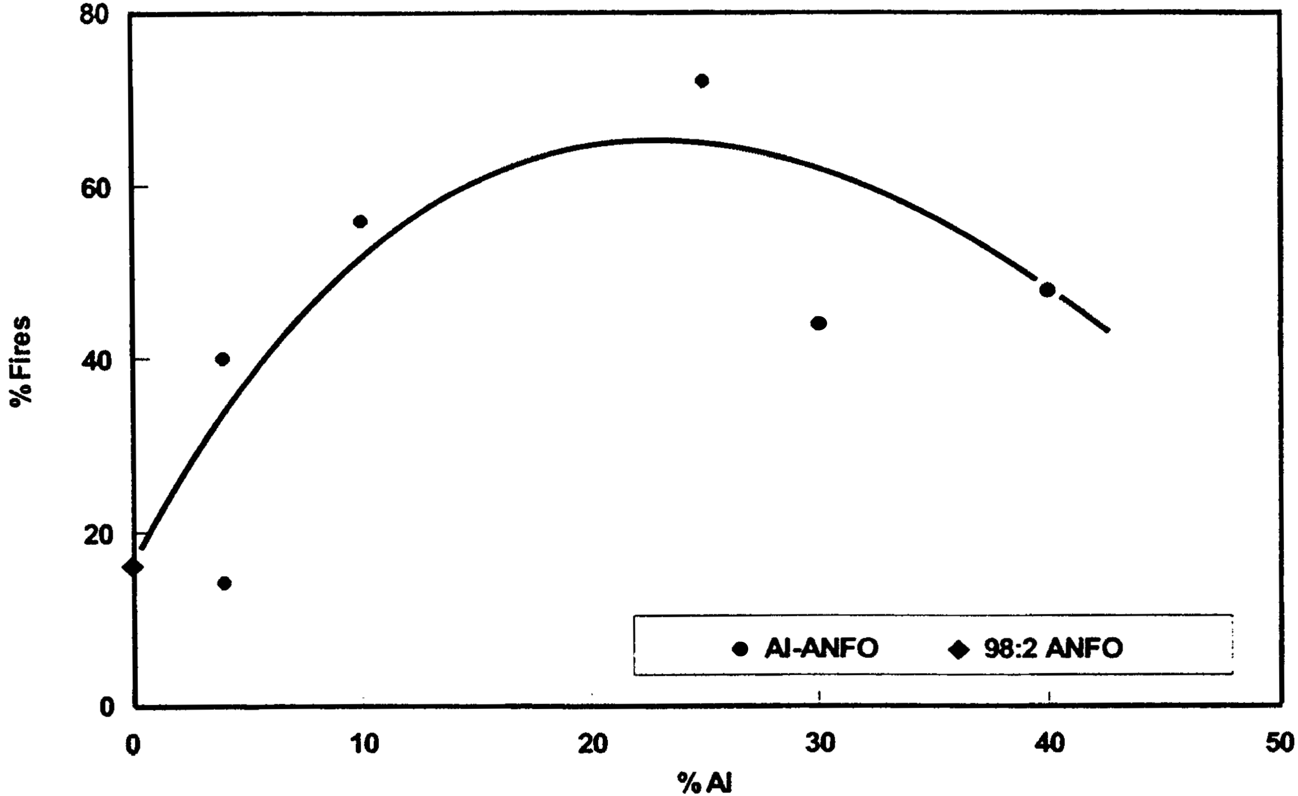

FIGURE 1

Dependence of the % fires in 50 drops from 237 cm (Rotter apparatus) on the proportion of 36/120 aluminium in Al-ANFO mixtures with a constant fuel oil content of 2%.

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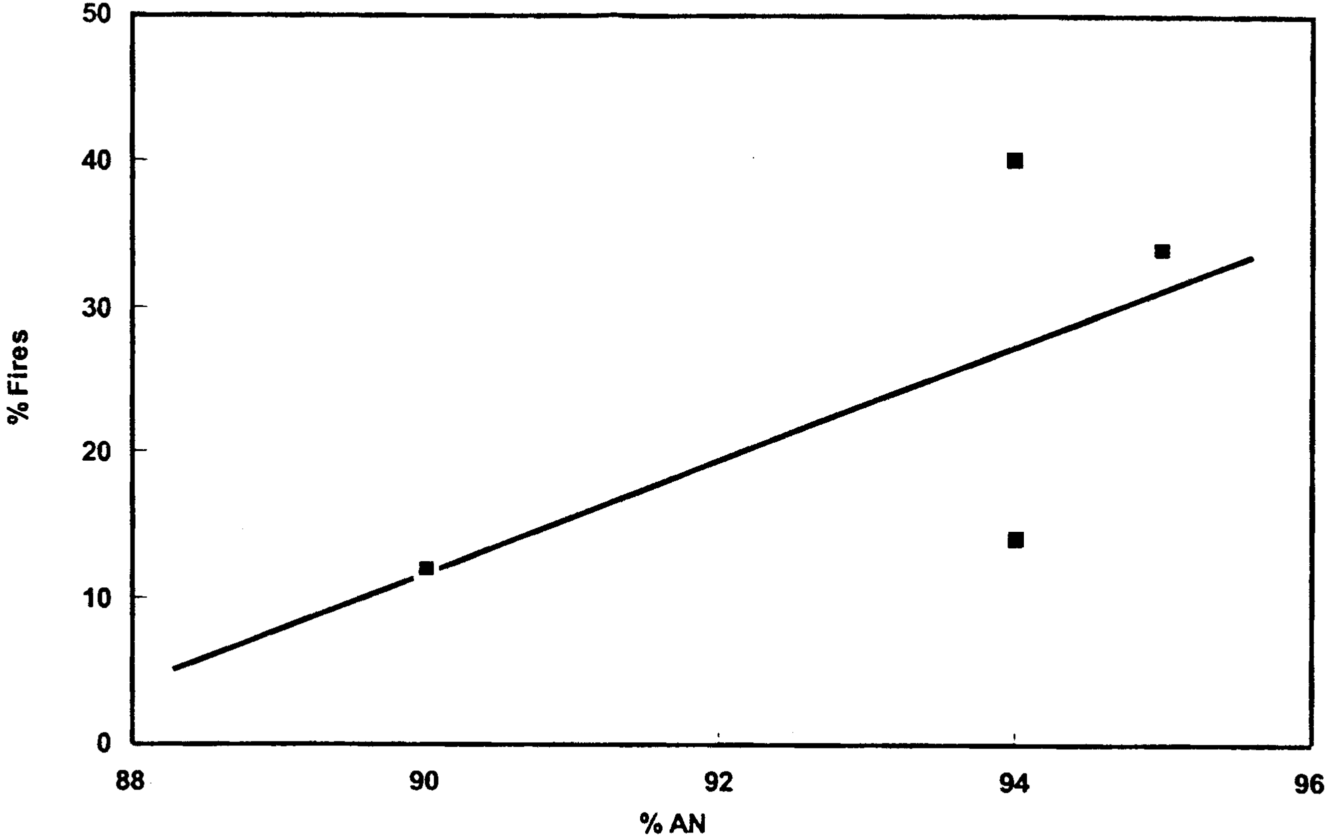

FIGURE 2

Dependence of the % fires in 50 drops from 237 cm (Rotter apparatus) on the proportion of AN in Al-ANFO mixtures in which Al was maintained at 4% (36/120 grade).

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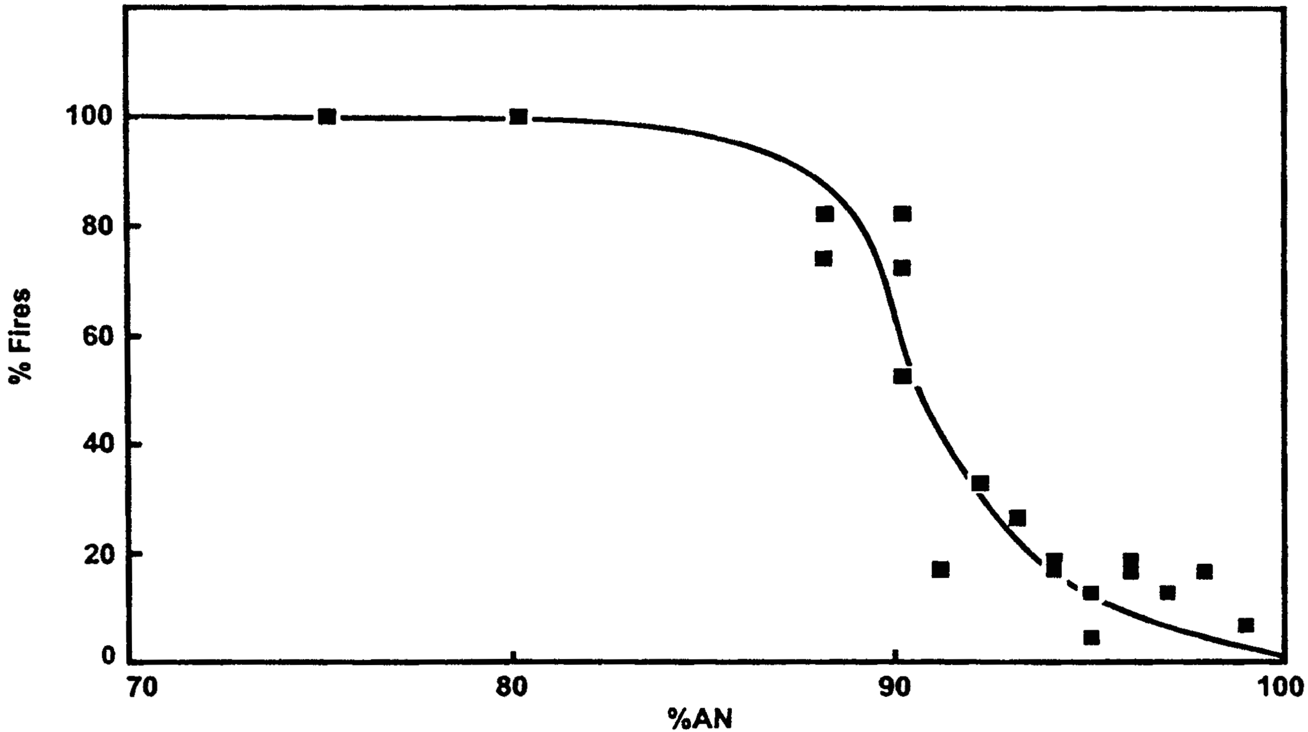

FIGURE 3

Dependence of the % fires in 50 drops from 237 cm (Rotter apparatus) on the proportion of AN in ANFO mixtures.

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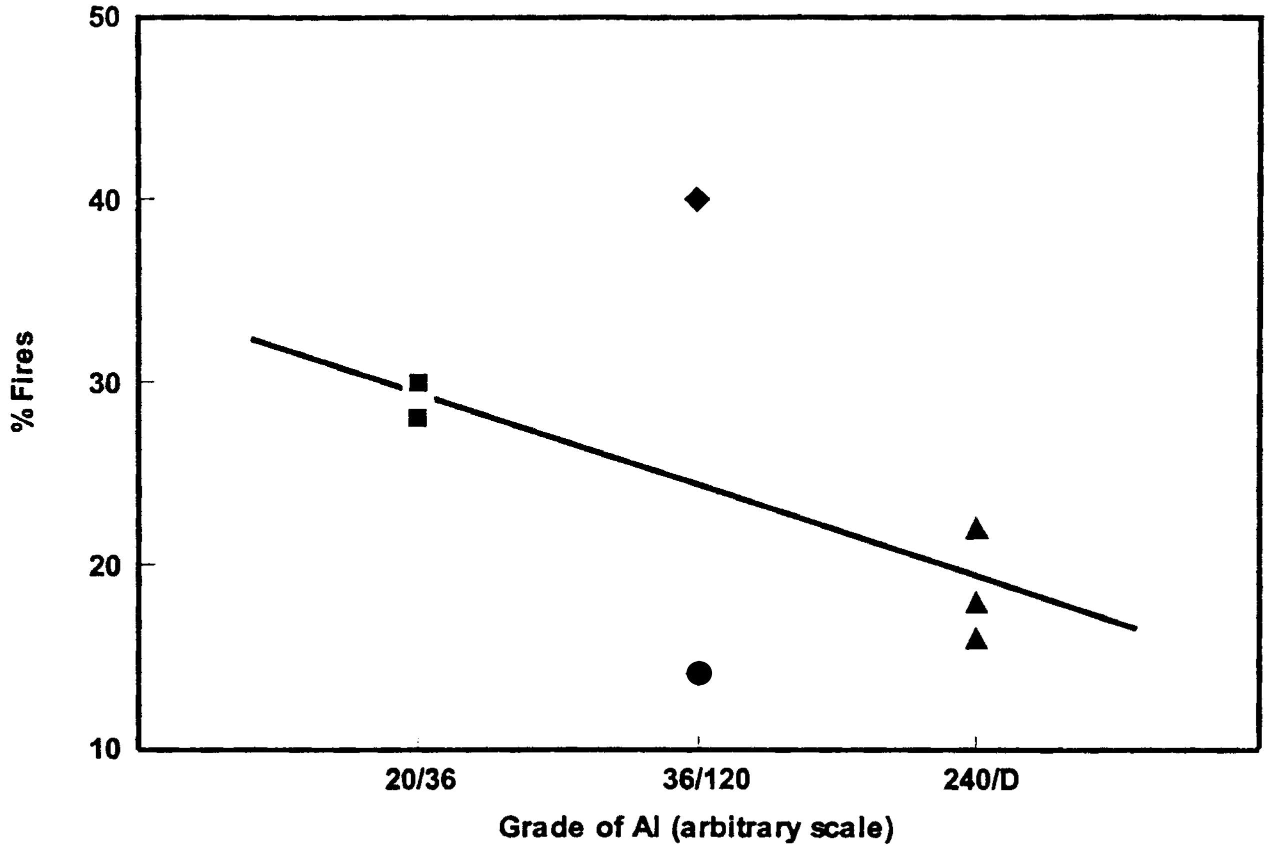

Dependence of the % fires in 50 drops from 237 cm (Rotter apparatus) on the grade of Al for Al-ANFO mixtures of composition 4:94:2.

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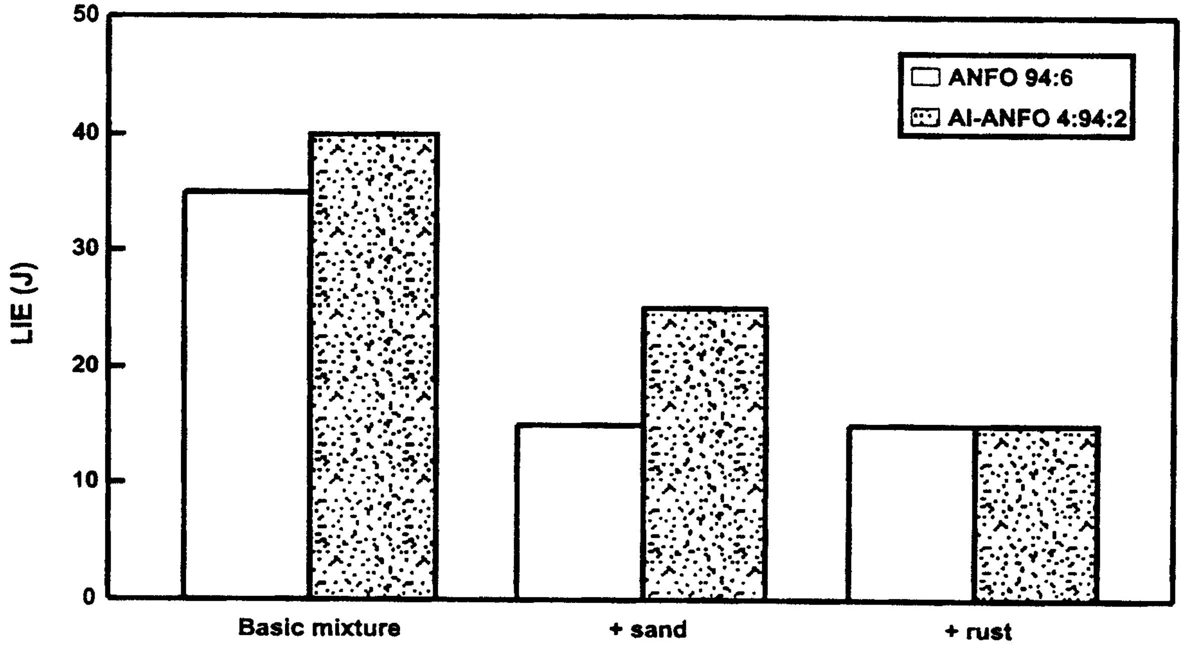

FIGURE 5

The effect of impurities on the impact sensitiveness (measured using the BAM Fallhammer apparatus) of ANFO and Al-ANFO mixtures with an AN content of 94%.