FIRE HAZARDS IN CHEMICAL PLANT FROM FRICTION SPARKS INVOLVING THE THERMITE REACTION

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SYNOPSIS

Impacts involving aluminium and rusty mild steel can initiate a thermite reaction. It is shown that the glancing impact of stainless steel, mild steel, brass, copper-beryllium, bronze, aluminium, copper, and zinc on to aluminium smears on rusty mild steel can initiate a thermite reaction of sufficient thermal energy to ignite flammable gas–air and solvent–air atmospheres and dust clouds typical of those found in the chemical industry.

The conditions of impact under which the different metals are most likely to produce an incendive thermite reaction are described.

The data indicate that although the No. 1 Wheeler Test and Godbert-Greenwald Furnace Ignition Temperatures of a dust cloud may not indicate its sensitivity to ignition by this form of friction " spark ", Class I dusts are much more likely to be ignited than Class II dusts.

Introduction

The potential fire hazard from friction " sparks " has been recognised for many years in the mining and petroleum industries (see bibliography). Experiments with methane–air mixtures have shown that a particularly dangerous form of friction " spark " can be produced by impacts involving aluminium and rusty mild steel because of the initiation of a thermite reaction.[35,36,41]

A thermite reaction can be produced by the simple action of striking an aluminium smear on a piece of rusty mild steel with a hammer. Burning aluminium particles produced in this manner are shown in Fig. 1. Sulphur dust scattered over the impact area can be readily ignited by the thermite reaction produced by impact (Fig. 2).

In order to assess more fully the potential hazard of this type of friction spark, experiments have been carried out to determine:

(*a*) the conditions under which a thermite reaction can be produced during glancing impacts between a metal and an aluminium smear on rusty mild steel, and

(*b*) the incendivity of the friction " spark " in the presence of flammable gas–air mixtures, solvent vapour–air mixtures, and chemical dust clouds.

Experimental Conditions

Apparatus

The apparatus used in this study is shown in Fig. 3; it consists essentially of a spring-loaded hardened steel hammer (weight 1·4 kg) which, when released, accelerates rapidly and strikes a nearly tangential glancing blow on the flat, horizontal, upper surface of a rusty mild steel block. Only the leading edge of the hammer head makes contact with the test sample. The test sample is clamped in a vice bolted to the upper surface of the lower plate. A rigid construction minimises any absorption of energy at the moment of impact by the relative movements of the various parts of the equipment.

The striking metal can be varied by fixing caps made from different metals on to the striking face of the hammer.

Rusty mild steel target and aluminium smear

The rusty targets were prepared by allowing the mild steel blocks to rust slowly under atmospheric conditions. The aluminium smear was produced by rubbing a piece of aluminium rod (aluminium content $>99{\cdot}5\%$) across the rusty steel surface under hand pressure until the smear contained the maximum amount of aluminium that would ahdere to the rusty surface. Rubbing the aluminium across the rusty surface produced a number of loose aluminium particles on top of the smear. It was found that a more extensive thermite reaction was obtained when these loose particles were allowed to remain in the impact area. The incendivity experiments were normally carried out with and without the loose aluminium in the impact area.

Impact conditions

A glancing blow that did not stop the forward movement of the hammer was found to be the most successful in initiating thermite reactions, and this type of impact was used throughout the investigations. A typical velocity profile for the hammer head during impact is shown in Fig. 4—the hammer head was in contact with the target surface for a distance of about three centimetres.

Production of the Thermite Reaction with Different Striker Metals

In order to assess whether or not the production of a thermite reaction was dependent on the material of the striker, metal caps made from stainless steel, mild steel, brass, copper-beryllium, bronze, aluminium, copper, and zinc were fitted in turn on to the striking face of the hammer.

Characteristics of metal strikers

An analysis of the major components in each metal, the Diamond Pyramid Hardness (D.P.H.) data and melting points of the metals are given in Appendix I.

Experimental procedure and results

The aluminium smears on the rusty mild steel target were struck glancing blows with each metal cap on the hammer

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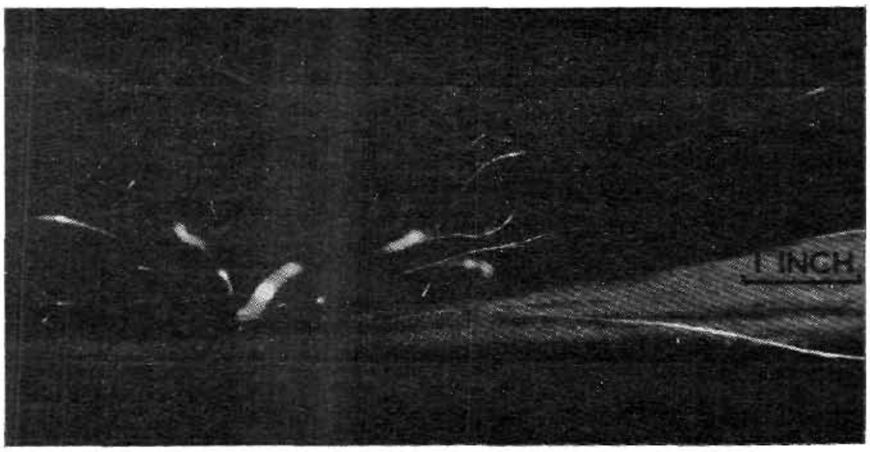


Fig. 1.—*Thermite reaction produced by hand-held hammer*

and a visual assessment made as to whether or not the impact produced a thermite reaction.

The visual evidence could be placed into one of three categories:

(*a*) No visible evidence of a spark of any kind—symbolised by N.

(*b*) A red spark similar in appearance to the spark produced when two metals impact in the absence of aluminium. When this occurred it was considered doubtful whether a thermite reaction had been initiated by the impact and even if it had, it had not propagated through the aluminium dust cloud—symbolised by S.

(*c*) A white flash indicating a propagating thermite reaction—symbolised by R.

All the metals produced thermite reactions but with the softer metals with lower melting points (*i.e.* aluminium, bronze, copper, and zinc) a thermite reaction did not occur at every impact. Photographs of two thermite reactions produced by each metal striker are shown in Figs 5 and 6. In one photograph of each pair background lighting has been used to show the position of the hammer. The size of the thermite reaction shown in the photographs should not be taken as characterising the relative magnitudes of the thermite reactions that are possible using the different metals because the size of the thermite reaction for each metal varied somewhat from impact to impact.

Two factors were found to be important in determining whether or not a reaction was produced.

(*a*) The presence of loose aluminium on the smear: this appeared to aid the initiation of a thermite reaction.

(*b*) The number of impacts to which the striking area on the hammer head had been subject: the zinc and aluminium hammer heads rarely, if ever, gave a thermite reaction on the first impact. However, if the same area of the hammer was used for a number of blows without being cleaned between each blow a thermite reaction could be produced. During repeated impact the softer metals become impregnated with aluminium and rust and this appears to aid the initiation of the thermite reaction. The effect of these two factors can be seen from the results given in Table I, for five successive impacts with each experimental situation.

The harder metals (stainless steel, mild steel, and brass) not only initiated reactions under all conditions of impact but also on the first impact. Because of their hardness there was little, if any, impregnation of the impact area by aluminium and rust and this was not necessary for a thermite reaction to be produced. Two reactions were obtained from five impacts with the copper striker having a clean surface and no loose aluminium. Five successive reactions were obtained with an impregnated surface. The same increase in reaction frequency was obtained from a clean surface when loose aluminium was present in the target area. The aluminium and bronze strikers did not give reactions under either condition with clean surfaces, but both readily initiated reactions when aluminium and rust had become embedded in the impacting faces. Five successive reactions could be obtained with the

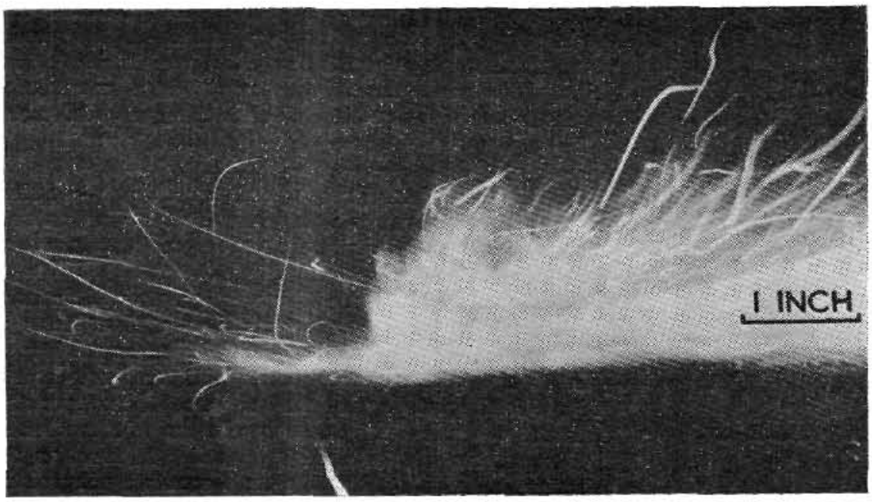


Fig. 2.—*Ignition of sulphur by frictional impact*

TABLE I.—*Effect of Cleaning Hammer Heads between Impacts*

Metal of hammer	Impact Condition			
	Clean Metal − loose Al	Impregnated Metal − loose Al	Clean Metal + loose Al	Impregnated Metal + loose Al
Bronze	NNNNN	RRRRR	NNNNN	RRRRR
Cu-Be	SRRRR	RRRRR	RRRRR	RRRRR
Stainless steel	RRRRR	RRRRR	RRRRR	RRRRR
Mild steel	RRRRR	RRRRR	RRRRR	RRRRR
Copper	RNRSN	RRRRR	RRRRS	RRRRR
Brass	RSRRR	RRRRR	RRRRS	RRRRR
Aluminium	NNNNN	RRRRR	NNNNN	RRRRR
Zinc	NNNNN	NNNNN	NNNNN	RRRRR

zinc hammer only when it had an impregnated striking surface and loose aluminium was present in the target impact area.

It cannot be concluded from these results that a thermite reaction could never be initiated under those conditions for which five successive non reactions were obtained. Nevertheless the results do show the relative frequency with which impacts involving the different metals can be expected to initiate a reaction under the different impact conditions. The results also indicate that, with soft metals, the chance of obtaining a reaction increases with the number of impacts between the hammer surface and the aluminium smear.

The other conclusion of importance is that the use of copper-beryllium in so-called " non-sparking " tools does not significantly decrease the possibility of a thermite reaction when the impact is on to aluminium-coated rusty mild steel.

The Incendivity of the Thermite Reactions

The incendivity of the thermite reactions produced by impacts involving the various metals has been examined using flammable coal gas–air, methane–air, acetone–air, toluene–air, and methanol–air atmospheres, and dust clouds.

Impacts were produced in each flammable atmosphere, a note made of the number of reactions that produced ignition, and the percentage of reactions causing ignition was calculated. If an impact did not initiate a thermite reaction then it was not included in the results.

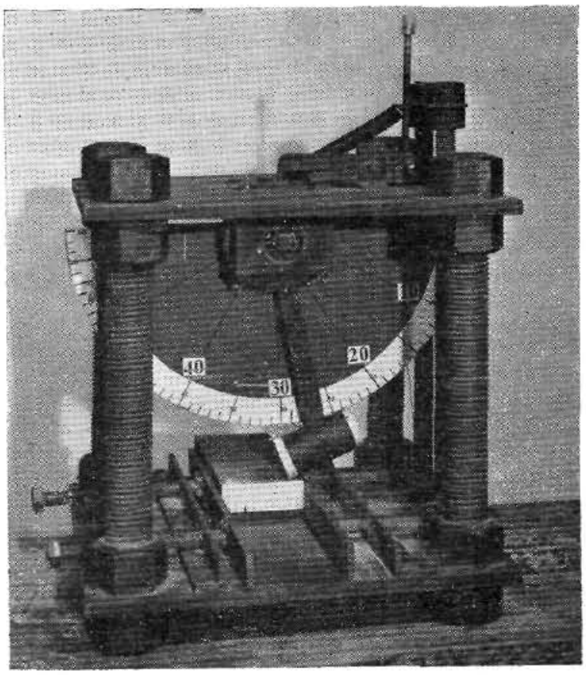


Fig. 3.—*Frictional impact apparatus*

Coal gas–air atmospheres

The glancing impact apparatus was enclosed in a metal explosion cubicle filled with coal gas–air mixtures of known concentration in the range 4–20% (v/v).

Thermite reactions produced by all the metals caused ignition of certain concentrations of the coal gas–air atmosphere and a similar relationship between percentage ignitions and coal gas concentration was obtained with each metal. The relationship shown in Fig. 7 obtained with the copper-beryllium striker is typical. Ignition was quickly obtained in every case once the gas concentration exceeded a certain minimum value. The minimum ignitable concentrations for the different metals were:

hardened mild steel, 5·0%
stainless steel, 5·0%
brass, 5·0%
copper, 5·0%
aluminium, 6·0%
copper-beryllium, 6·0%
bronze, 6·0%
zinc, 6·0%.

All the minimum concentrations on the threshold of ignition are at or just greater than the lower limit of flammability of coal gas–air atmospheres (5%). The thermite reactions produced in impacts involving the four metals with the lowest D.P.H. hardness ratings—namely, aluminium, copper-beryllium, bronze, and zinc—required slightly greater concentrations of coal gas before ignition was obtained and could therefore be considered less incendive than those from the harder metals. The change in coal gas concentration from 5% to 6% to give ignition is however too small to be of any practical significance. It must be concluded that when the concentration of coal gas is above the lower limit of flammability the thermite reaction produced by the impact of any of the metals tested could ignite the flammable atmosphere.

Methane–air atmospheres

The equipment and test method for methane–air atmospheres were identical with those used in the coal gas experiments. Methane–air mixtures in the concentration range 4%–15% (v/v) were examined.

Rae has shown[37] that strikers made from steel, brass, and aluminium can ignite methane–air atmospheres. Tests were only carried out therefore on the metals not used by Rae (*i.e.* bronze and copper-beryllium) and on zinc, the metal with which he could not obtain ignitions. The copper striker was not available during the experiments with methane.

The experimental results were similar in form to those obtained with coal gas. The three metals again produced

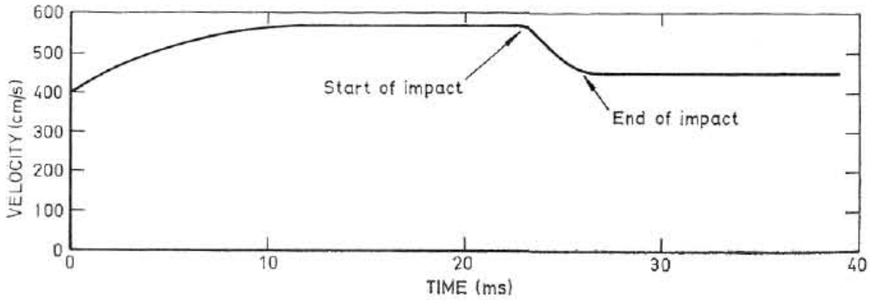


Fig. 4.—*Velocity profile of hammer head during impact*

thermite reactions that could ignite the flammable atmosphere provided the methane concentration was above a certain minimum value (zinc, 6·2%; copper-beryllium, 5·3%; bronze, 6·1%). The lower flammability limit of methane–air is 5·3%: thus, as with coal gas, it can be concluded that for all practical purposes the thermite reaction can ignite methane–air mixtures in the flammable concentration range. Thermite reactions and ignitions were only obtained with the zinc striker after it had become impregnated with aluminium and rust by contact with the aluminium smear.

Solvent vapour–air atmospheres

Flammable acetone–air, toluene–air, and methanol–air atmospheres were used to test the possibility of ignition with solvents. The concentrations of acetone and toluene were 4·7% and 2·3% respectively. The concentration of methanol vapour tended to vary due to condensation in the explosion chamber. A reaction giving non-ignition was not included in the data if an electric spark released in the impact area immediately after impact did not cause ignition.

The incendivity was determined with and without loose aluminium on the mild steel target. The experimental results from five successive thermite reactions are summarised in Table II.

These results indicate that if the impact involving any of these metals except zinc produces a thermite reaction then ignition of a surrounding flammable vapour–air atmosphere will almost certainly follow. With a zinc striker it is more difficult to produce a thermite reaction but when this occurs there is a reasonable probability that ignition will follow although it is possible to produce a small thermite reaction that does not propagate throughout all the combustible aluminium and which does not generate sufficient heat to ignite these solvent vapour–air atmospheres.

Clouds of chemical dust

A wide number of powder products manufactured in the chemical industry, whilst not explosives, can form dust clouds that can burn with explosive violence when exposed to a source of ignition (*e.g.* a hot surface, an electric spark) in a confined space.

The sensitivity of a dust cloud to ignition by a heat source can be measured by the No. 1 Wheeler Test and the Godbert-Greenwald Furnace Test. A dust cloud that ignites in both the No. 1 Wheeler and the Godbert-Greenwald Furnace Test is classified as Class I, a dust cloud that does not ignite in the No. 1 Wheeler Test but ignites in the Furnace Test is classified as Class II. A dust cloud that does not ignite in either test is classified as Class III and will not ignite in normal manufacturing processes.

In order to determine whether the thermite reaction produced during impact is a potential source of ignition, thermite reactions have been produced in dust clouds from 95 products, selected to be representative samples of Class I and II dusts. In all the tests the stainless steel striker was used to produce the thermite reaction.

A dust cloud of the powder under test was produced by placing a small cone-shaped heap of powder on the mild steel target at the edge of the impact area (Fig. 8). As the hammer moves in an arc it strikes the aluminium smear a glancing blow, initiates the thermite reaction, and projects burning aluminium particles forward. These pass through the dust cloud produced as the hammer continues its forward movement and strikes the heap of powder.

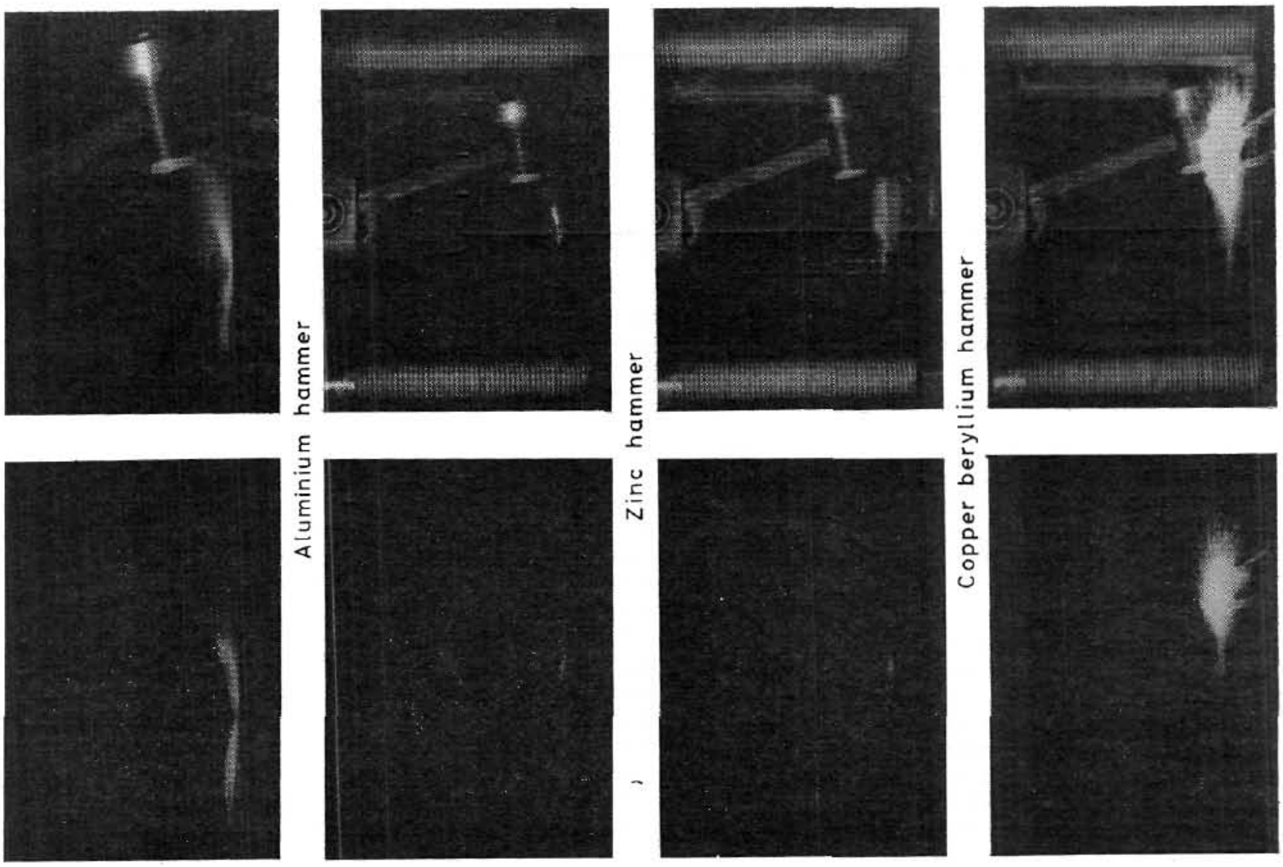
Up to five attempts were made to ignite each powder; if ignition occurred before the fifth reaction the tests were stopped and the number of the reaction that caused ignition was noted. If ignition did not occur after five reactions " no ignition " was recorded. The visual evidence after impact depends not only on whether or not ignition occurs, but also on the form in which the burning is propagated through the dust cloud. It was possible to divide the results into three categories:

(1). Those in which, after impact, flame propagated clear of the region of the thermite reaction, in some cases up to distances of two to three feet. This evidence indicated that

TABLE II.—*Results of Impacts in Solvent vapour–air Atmospheres*

	Acetone		Toluene		Methanol	
Metal	With loose Al	Without loose Al	With loose Al	Without loose Al	With loose Al	Without loose Al
Stainless steel	IIIII	IIIII	IIIII	IIIII	IIIII	IIIII
Mild steel	IIIII	IIIII	IIIII	IIIII	IIIII	IIIRI
Brass	IIIII	IIIII	IIIII	IIIII	IIIII	RIIII
Copper	IIIII	IIIII	IIIII	IIIII	IIIII	IIRII
Cu-Be	IIIII	IIIII	IIIII	IIIII	IIIII	IIIII
Bronze	IIIII	IIIII	IIIII	IIIII	IIIII	IIIII
Aluminium	IIIII	IIIII	IIIII	IIIII	IIIII	IIIII
Zinc	IIIII	RIIRI	RIIII	IIRRI	IRIII	IIRII

Symbols: I—ignition of flammable atmosphere.
R—visible thermite reaction but no ignition of flammable atmosphere.



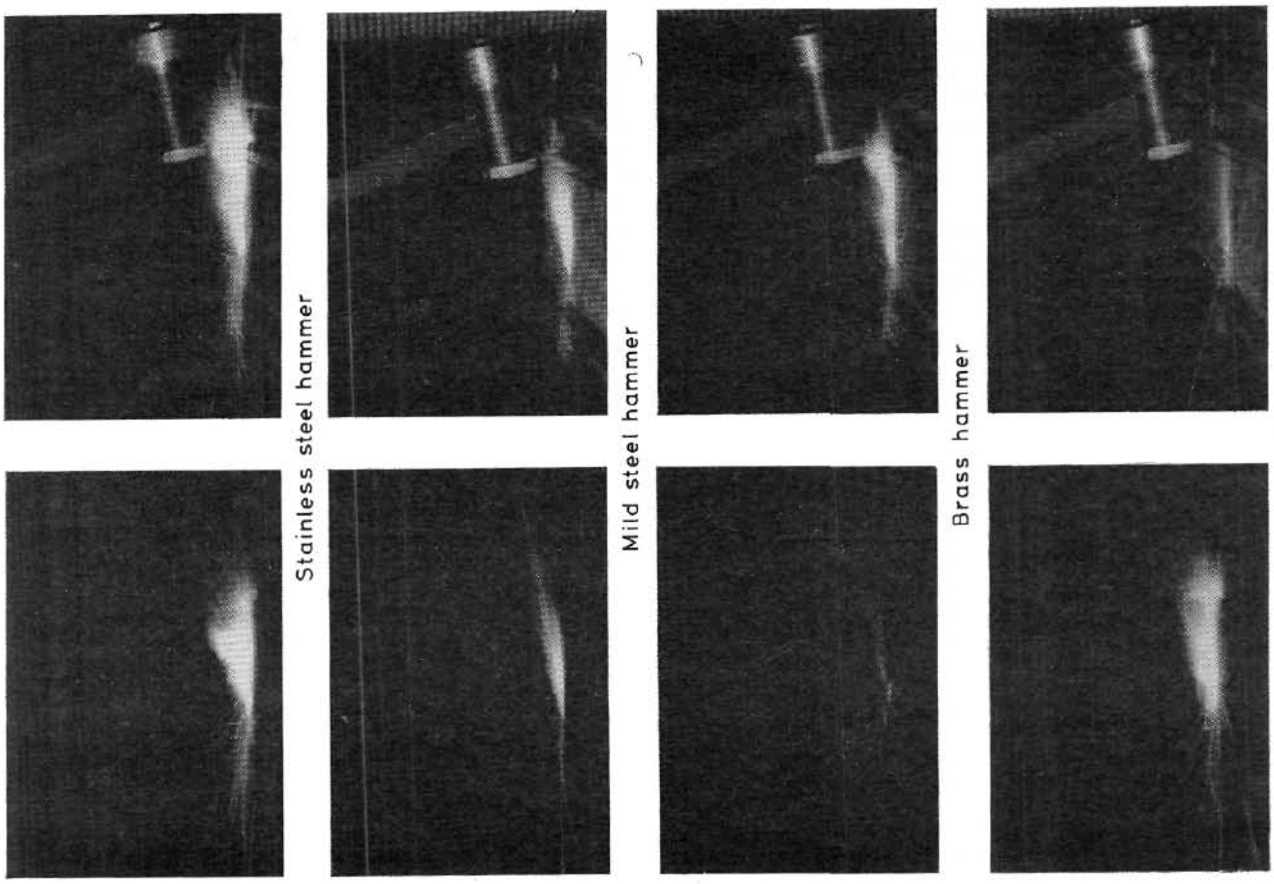
Aluminium hammer

Zinc hammer

Copper beryllium hammer

Bronze hammer

Fig. 6.—*Thermite reactions produced by different striker metals*



Stainless steel hammer

Mild steel hammer

Brass hammer

Copper hammer

Fig. 5.—*Thermite reactions produced by different striker metals*

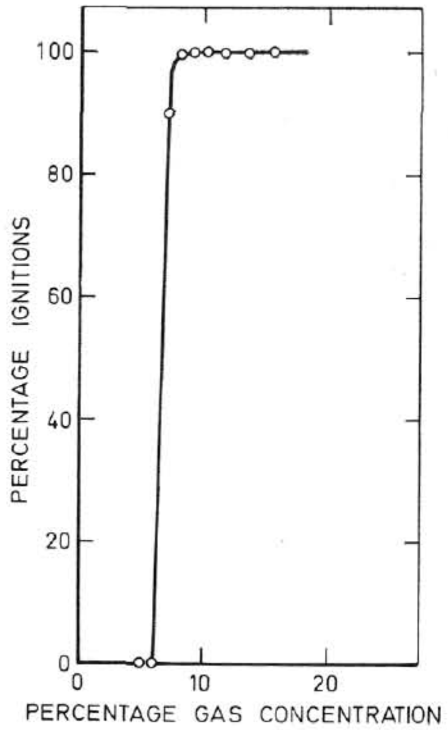


Fig. 7.—*Percentage ignition/coal gas-air concentration. Copper-beryllium hammer, mixture of coal gas and air*

not only could the product be ignited by the thermite reaction but also that the combustion would propagate through a dust cloud of the material. These results were recorded as I/P with a suffix on I denoting the reaction at which ignition occurred.

(2). Those in which flame, distinct from the thermite white " flash " could be seen but in which the propagation was less than two to three inches long. These results were recorded as I/NP with an appropriate suffix on I.

(3). The third type was that in which no evidence of flame or propagation was seen—recorded as a non-ignition and symbolised by N_5. In this category were included a few products that were charred by the burning aluminium but where there was no evidence that the powder had sustained the combustion.

The data for the 95 dusts tested are summarised in Table III. This table shows that 46 of the 95 dusts tested were ignited by the thermite reaction and 27 of these propagated the burning outside the impact area. Fig. 9 shows the ignition of a powder categorised as I/P. This powder is typical of many processed in the chemical industry—No. 1 Wheeler Test temperature 975°C, Godbert-Greenwald Furnace Temperature 550°C.

The classification of a test result as propagating or non-propagating requires some comment. The initiation of burning and its subsequent propagation depends not only upon the sensitivity of the product but also on the form of the dust cloud into which the burning aluminium is projected. The present method of producing a dust cloud by the hammer movement is far from ideal. Under certain plant conditions (*e.g.* in the filter bag of a grinding unit or during pneumatic transfer) powders that were not well dispersed by the hammer movement could be entrained in the air in sufficient quantity to form a combustible mixture capable of propagating fire or explosion. Some caution is necessary therefore in using the data in Table III as an indication of the distribution of sensitivities within a group of typical products. For products categorised as I/P a thermite reaction in the presence of a combustible mixture of the dust in air could clearly cause a propagating fire or explosion. With products categorised as I/NP it may well be that the absence of flame propagation was due to the poor dust dispersion produced in the test equipment and not due to an intrinsic inability of the product to propagate flame. On the other hand the product may not in fact be capable of extensive propagation of fire, and a thermite reaction or any other local ignition source could only cause a localised fire. For the same reason categorisation of a product as N_5 should not be taken as conclusive evidence that ignition could not occur under all conditions of dust dispersion.

Despite this imprecision, the results do indicate that the thermite reaction resulting from the impact of the metal onto an aluminium-coated rusty mild steel surface can ignite a significant proportion of the dust clouds present in powder manufacturing units.

The results also showed that the majority of dusts that were ignited were from Class I powders; out of 42 Class II powders tested only one ignited. Plots of the sensitivity ratings of the samples to ignition by the thermite reaction (*i.e.* I_1, I_2, I_3, I_4, I_5, and N_5) against the Godbert-Greenwald and No. 1 Wheeler ignition temperatures failed however to show any precise relationship between these variables (see Figs 10 and 11). It is known that the relative sensitivity of dust clouds from different powders depends very much on the nature of the source of ignition; this lack of correlation between ignitions obtained with the thermite reaction and the No. 1 Wheeler and Godbert-Greenwald Furnace Test is not therefore unexpected. It does mean, however, that the ignition temperatures determined on these latter tests cannot be used to assess the sensitivity of a powder to ignition by a thermite reaction.

Source of ignition

The experiments with dust clouds show that although the major part of the thermite reaction occurs in the impact area the burning particles of aluminium projected clear of this area can act as sources of ignition. In these experiments a number of discrete burning particles were projected over distances greater than 12 in. from the impact area. The weight distribution of particles projected clear of the impact area in this apparatus is shown in Fig. 12. Although the majority of the particles are in the weight range 1–8 μg, individual particles weighing up to 16 μg were found.

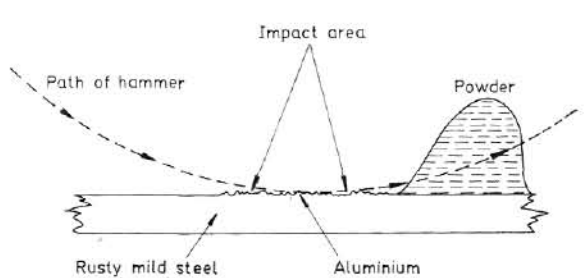


Fig. 8.—*Schematic diagram showing position of impact area and powder under test.*

TABLE III.—*Test Results on Dust Clouds*

Test Result	I_1/P	I_2/P	I_3/P	I_4/P	I_5/P	I_1/NP	I_2/NP	I_3/NP	I_4/NP	I_5/NP	N^5
No. of Samples	25	1	1	0	0	16	2	1	0	0	49

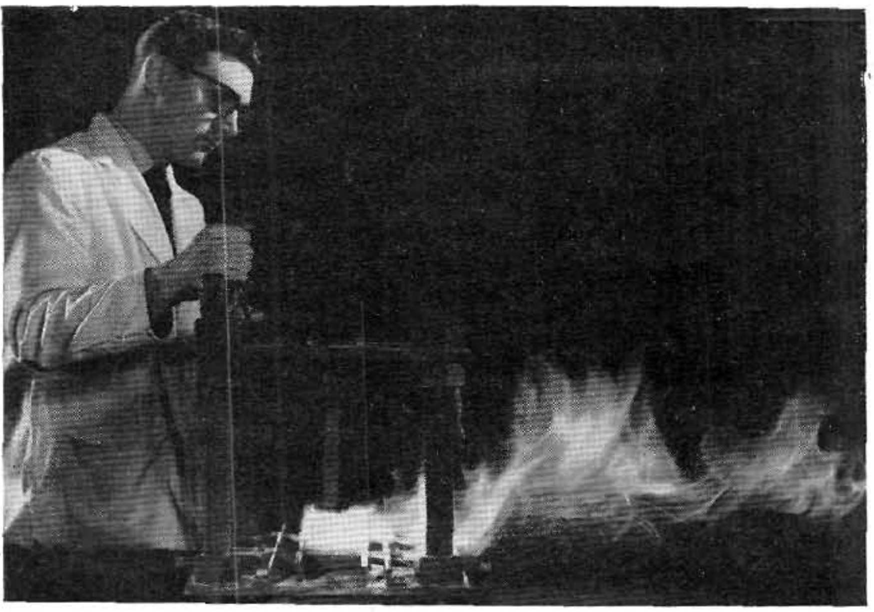


Fig. 9.—*Ignition of powder sample*

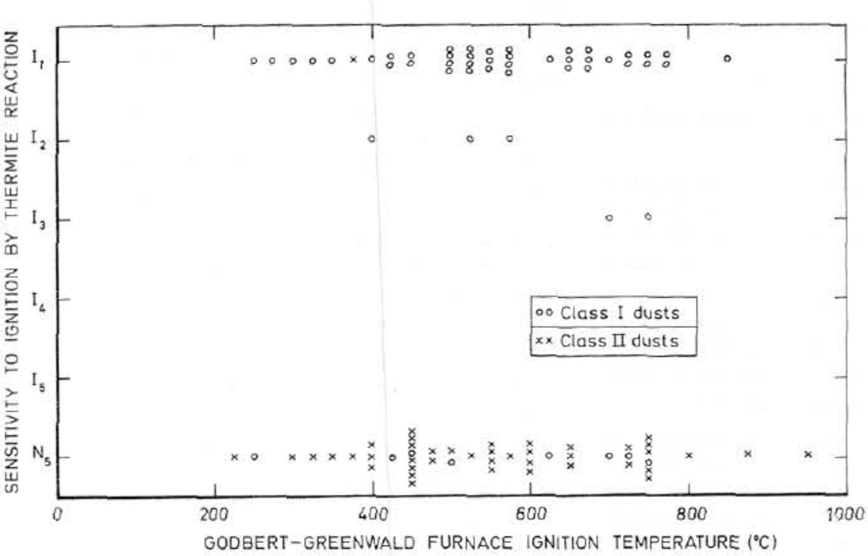


Fig. 10.—*Comparison of sensitivity to ignition by thermite reaction and Godbert-Greenwald furnace ignition temperature*

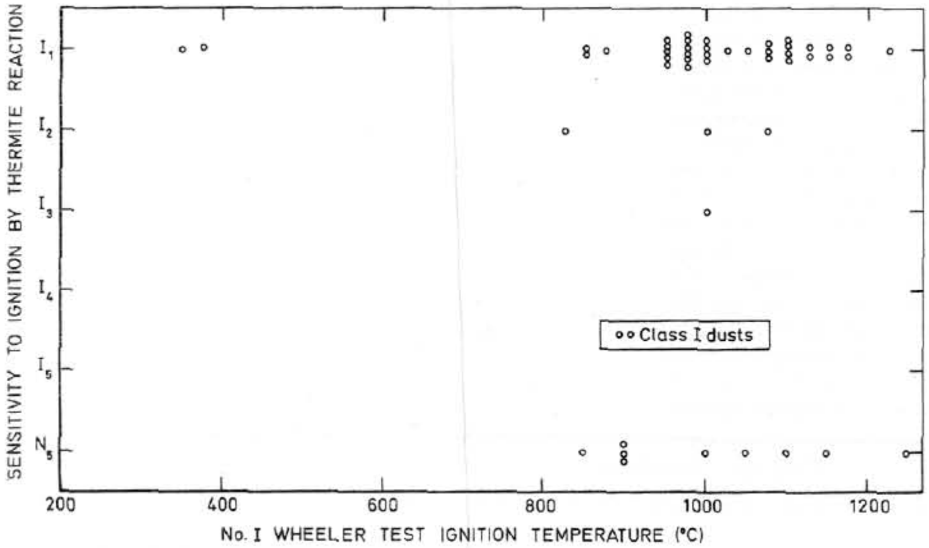


Fig. 11.—*Comparison of sensitivity to ignition by thermite reaction and No. I Wheeler test ignition temperature. Class I dusts*

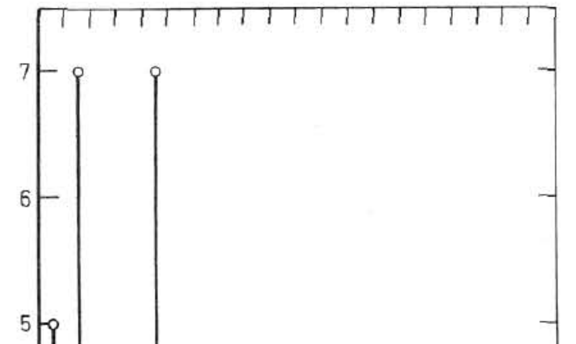


Fig. 12.—*Weight distribution of burning particles projected clear by impact area*

Bowden and Lewis[7] have shown that the minimum weight of an aluminium particle capable of igniting 5%–9% methane–air atmosphere is 1 μg and tests by ourselves have shown that less than 7 μg of aluminium is required to ignite the stoichiometric vapour–air mixtures of acetone, toluene, and methanol. This is of practical importance in that impacts outside a flammable atmosphere, *e.g.* on the outer surface of a reaction vessel, can still initiate a fire if burning particles of aluminium are projected into the flammable atmosphere *e.g.* enter a reaction vessel via the charge hole.

Conclusions

1. The glancing impact of stainless steel, mild steel, brass, copper-beryllium, bronze, aluminium, copper, and zinc on to aluminium smears on rusty mild steel can initiate a thermite reaction and cause the ignition of flammable gas and solvent atmospheres and dust clouds formed from certain powders (particularly Class I products) manufactured in the chemical industry.

2. The sources of ignition are:

(*a*) a dense cloud of burning aluminium immediately surrounding the point of impact, and

(*b*) individual particles of burning aluminium that may be projected some distance from the point of impact.

It is not necessary for the impact to be in the flammable atmosphere for ignition to occur. Individual particles of mass greater than 7 μg are capable of igniting flammable solvent and gas atmospheres.

3. Incendive thermite reactions could be produced by all the metals examined but the proportion of impacts that caused an incendive reaction was less for the metals of low hardness and low melting point. Soft metals (*e.g.* aluminium and zinc) are more likely to initiate a thermite reaction if the striking surface is impregnated with rust and aluminium from previous impacts.

4. The use of " non sparking " tools made from copper-beryllium does not significantly decrease the possibility of a dangerous friction " spark " when the impact is on to aluminium-coated rusty mild steel.

5. In the case of powder products, present evidence indicates that the No. 1 Wheel Test and Godbert-Greenwald Furnace ignition temperatures do not provide a measure of the sensitivity of the product to ignition by the thermite reaction.

6. For a thermite reaction produced by impact to initiate a fire in a plant the following conditions must be satisfied:

(1). Not only must aluminium and rust be present in the area but they must also come into contact to produce a smear of aluminium on a rusty metal surface.

(2). The aluminium smear must be struck a blow by a second object—if the striker is aluminium it is possible for the smear and the thermite reaction to result from the same blow or from two blows in succession.

(3). The subsequent thermite reaction must occur in or propagate into a flammable atmosphere.

If any one of these conditions is not fulfilled a fire cannot occur. The probability of fulfilling all three conditions will vary from plant to plant and will depend on the nature of the plant, its mode of operation and the type of product being manufactured. A separate assessment of the hazard is therefore required for each plant/product combination in order to ensure safe operation and yet not impose unnecessary restrictions on the use of aluminium.

References and Bibliography

[1] Anon. " *Sparks from Hand Tools* ", 1956. (New York: American Petroleum Institute).

[2] Anon. " *Ampco Spark-resistant Tools. Spark Resistance. Results of Comparative Tests of Material* ", 1959. (Milwaukee: Ampco).

[3] Anon. " *Report of the Fire Research Board with the Report of the Director of Fire Research* ", 1962, p. 65. (London: H.M.S.O.).

[4] Anon. *Report NSS* 651–200/1958. (New York: N.Y. Naval Shipyard).

[5] Allsop, G. A. *Trans. Instn min. Engrs*, 1938/9, **96**, 310.

[6] Anfenger, M. B., and Johnson, C. W. *Proc. Am. Petrol. Inst.*, 1941, **22,** 54.

[7] Bailey, J. C. *Trans. Instn min. Engrs*, 1958/9, **118,** 223,

[8] Bernstein, H. and Young, G. C. *Report NGF/T/1/57.* (Washington: U.S. Department of Commerce, Office of Technical Services).

[9] Bowden, F. P. and Lewis, R. D. *Engineering, Lond.*, 1958, **186,** 241.

[10] Bowden, F. P. and Ridler, K. E. W. *Proc. R. Soc.*, 1936, **A154,** 640.

[11] Bowden, F. P., Stone, M. A., and Tudor, G. K. *Proc. R. Soc.*, 1946/47, **A188,** 329.

[12] Brenner, P. and Eversheim, P. *Glückhauf*, 1958, **94,** 180.

[13] Burgess, M. J. and Wheeler, R. V. *Pap. Saf. Mines Res. Bd*, 46/1928.

[14] Burgess, M. J. and Wheeler, R. V. *Pap. Saf. Mines Res. Bd*, 54/1929.

[15] Burgess, M. J. and Wheeler, R. V. *Pap. Saf. Mines Res. Bd*, 62/1930.

[16] Burgess, M. J. and Wheeler, R. V. *Pap. Saf. Mines Res. Bd*, 70/1931.

[17] Burgess, M. J. and Wheeler, R. V. *Pap. Saf. Mines Res. Bd*, 81/1933.

[18] Coward, H. F. and Guest, P. G. *J. Am. chem. Soc.*, 1927, **49,** 2479.

[19] Coward, H. F. and Wheeler, R. V. *Pap. Saf. Mines Res. Bd*, 53/1929.

[20] Demelenne, E. *Annls Mines Belg.*, 9162, **7/8.**

[21] Dittman, P., Voigtsberger, P., and Schulz, F. *Arbeitschutz*, 1960, **8,** 180.

[22] Evans, W. H., Jeffrey, R., and Titman, H. *Res. Pap. Saf. Mines Res. Bd*, 114/1955.

[23] Grice, C. S. W. *Res. Pap. Saf. Mines Res. Bd*, 59/1952.

[24] Harrison, P. L. and Yoffe, A. D. *Proc. R. Soc.*, 1961, **A261,** 357.

[25] Hartmann, I. *Bureau of Mines Information Circular* 7727/1955. (Washington: Department of the Interior).

[26] Kingman, F. E. T., Coleman, E. H., and Rogowski, Z. W. *J. appl. Chem., Lond.*, 1952, **2,** 449.

[27] Kocherga, N. G. *Nauchno-issledouatel'skie raboty Mak N.II Za*, 1959/60, p. 99.

[28] Konschak, M. and Voigtsberger, P. *Arbeitschutz*, 1957, **11,** 214.

[29] Latin, A. *Colliery Engng*, 1959, **34,** 397.

[30] Margerson, S. N. A., Robinson, H., and Wilkins, H. A. *Res. Pap. Saf. Mines Res. Bd*, 75/1953.

[31] McCombe, J. *Jl R. tech. Coll. Glasg.*, 1933/6, p. 173.

[32] Nagy, J. and Kawenski, E. M. *Bureau of Mines Report of Investigation* 5548. (Washington: Department of the Interior).

[33] Paterson, S. *Phil. Mag.*, 1939, Ser. 7, **28,** 2: *Idem ibid.*, 1940, Ser. 7, **30,** 437.

[34] Pechuk, E. I. in " *Problems of Mining Electro-mechanics* ", 160, Third Edition. **Vol. 11.**

[35] Rae, D. *Res. Pap. Saf. Mines Res. Bd*, 129/1956.

[36] Rae, D. *Res. Pap. Saf. Mines Res. Bd*, 177/1959.

[37] Rae, D. *Res. Pap. Saf. Mines Res. Bd*, 190/1960.

[38] Rae, D. *Combust. Flame*, 1961, **5,** 341.

[39] Rae, D. *Res. Pap. Saf. Mines Res. Bp.* (In preparation).

[40] Rae, D. and Nield, B. J. *Res. Pap. Saf. Mines Res. Bd*, 192/1960.

[41] Rae, D., Singh, B., and Danson, R. *Res. Pap. Saf. Mines Res. Bd.* (In preparation).

[42] Riddlestone, H. G. and Bartels, A. *J. Inst. Petrol.*, 1965, **51,** 106.

[43] Rosenblek, B. *Bergb.-Arch.*, 1960, **21,** 61.

[44] Schreiter, W. *Chem. Tech. Berl.*, 1953, **5,** 708.

[45] Schultze-Rhonof, H. *Glückhauf*, 1956, **92,** 777.

[46] Schultze-Rhonof, H., and Weichsell, L. *Mitt. westf. Bergwerksch-Kasse*, 1951, **1,** No. 2.

[47] Silver, R. S. *Phil. Mag.*, 1937, **23,** 633.

[48] Thomas, T. S. E. *Colliery Guard.*, 1941, **163,** 202.

[49] Thomas, W. G. *Colliery Engng*, 1962, **39,** 377.

[50] Thompson, W. and Titman, H. *Res. Pap. Saf. Mines Res. Bd*, 60/1964.

[51] Titman, H. *Res. Pap. Saf. Mines Res. Bd*, 90/1954.

[52] Titman, H. *Trans. Instn Min. Engrs*, 1955–56, **115,** 535.

[53] Titman, H. and Wynn, A. H. A. *Res. Pap. Saf. Mines Res. Bd*, 95/1954.

[54] Weichsel, L. *Glückhauf*, 1955, **91,** 1048.

[55] Wynn, A. H. A. *Res. Pap. Saf. Mines Res. Bd*, 42/1952.

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Appendix I

Description of Striker Metals

Metal	Major Constituents (%)	Approximate Melting Point (°C)	Hardness		
			D.P.H. Data		Remarks
			Load (kg)	Hardness	
Stainless steel	Fe 72 Cr 17·5 Ni 8	1450	30	224	The hardness of the grades of austenitic chromium nickel steel that are widely used in the chemical industry is 200 D.P.H. maximum in the fully softened condition in which they are usually supplied.
Mild steel	Fe 99·9	1530	10	177	Ordinary low-carbon mild steel which is in the normalised condition would have a hardness of about 100–120 D.P.H. This material is probably in a cold worked condition.
Brass	Cu 57 Zn 40	900	10	144	In the annealed condition brass would have a hardness in the range 65–75 D.P.H. This sample is in a work hardened condition.
Cu-Be	Cu 98 Be 2	975	10	140	This sample was machined from the head of a " non-sparking " hammer. The fully heat treated alloy that would be used for chisels, etc., could have a hardness of 350 D.P.H.
Bronze	Cu 87 Sn 10	1032	10	110	This is the order of hardness expected in a chill cast 10% tin-bronze commonly used for bearings, *etc.*
Aluminium	Al >99 Mg <0·1	660	10	106	Typical value for heat treatable alloy in fully heat-treated (WP) condition.
Copper	Cu >99	1083	2·5	54	Typical of commercially pure copper in the annealed (soft) condition.
Zinc	Zn >99	420	2·5	40	This is a " mean " value; the hardness varied according to the direction it was determined relative to the internal structure of the metal.

DISCUSSION

Mr. F. J. Owen asked if there was a thermite reaction if there was rust on aluminium instead of the other way round, and if so had this been investigated?

Dr. Gibson said that it had never been done. Aluminium was such a soft metal that it was very difficult to get rust to stay on it for any length of time.

Dr. H. S. Eisner welcomed the paper because it was clear that the aluminium hazard described by Gibson was still not as well known throughout industry as it deserved to be. One still came across the belief that, on the contrary, aluminium was a " non-sparking " metal. Indeed, kits of so-called non-sparking tools containing some that were made of aluminium were still on sale. In the petroleum and gas industries the use of aluminium containing several per cent of magnesium (which increased the hazard) was rapidly gaining ground. The safe use of those materials depended on the constant awareness of the hazard by all concerned in the design, construction and use of equipment made of them.

Answering Mr. Owen's question, he thought that if the conditions of impact were right it would be possible to obtain a thermite reaction when powdered rust placed on aluminium was struck by an external striker.

Mr. P. L. Klaassen asked what was Gibson's attitude towards the use of aluminium paint. Moisture caused rust behind the paint and could thus create possibly the right mixture for ignition.

Dr. Gibson replied that aluminium paint had not been examined by himself and Messrs Lloyd and Perry. Much work had been done on this by the Safety in Mines Research Establishment. His department tended to follow them. As far as aluminium paint on objects was concerned, it depended on the base of the paint; some were safer than others. At present, in his department, they tended not to use them if they could avoid it but there was a tradition in the chemical industry to use aluminium paint. He was in a research department and there was a credibility gap between them and the engineers. He did not think that was peculiar to ICI but it was fairly common. He did not wish anyone to get the wrong impression; they were not saying " Don't use the aluminium ", they were saying: " This could be a danger and it should be used sensibly."

Mr. Z. W. Rogowski said that he worked on fire dangers in respect of use of aluminium paint many years ago. Sixteen commercial paints of various compositions were tested and the results indicated that whether the incendive sparks would be produced depended very much on the vehicle incorporated into the paint. No commercial paint produced incendive sparks unless heated. As a result of this work certain recommendations were issued by Factory Inspectorate and some restrictions were placed on paints based on cellulose nitrate. It should be noted that since then aluminium paints of other compositions had appeared on the market.

Dr. Gibson said that the work he was thinking of was the work of Grice at SMRE (Ref. 23 of the paper). He suggested in his report that the surface did not need to be heated and that there was sufficient heat from the impact to cause ignition. That was an important point. Very often one could paint a cold surface—not a radiator or steam pipe—and Grice had pointed out that the impact itself would give sufficient heat and no prior heating was needed.