THE EXPLOSIVE CHARACTER OF ZINC DUST
A CASE STUDY

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ABSTRACT

Fine powders normally exhibit, to a more or lesser extent, some ability to participate in dust explosions. Zinc dust as used in the extractive metallurgy of zinc, is not known to be a reactive powder in the industry. No evidence could be found in the literature where zinc dust was involved in an explosion or explosive type event.

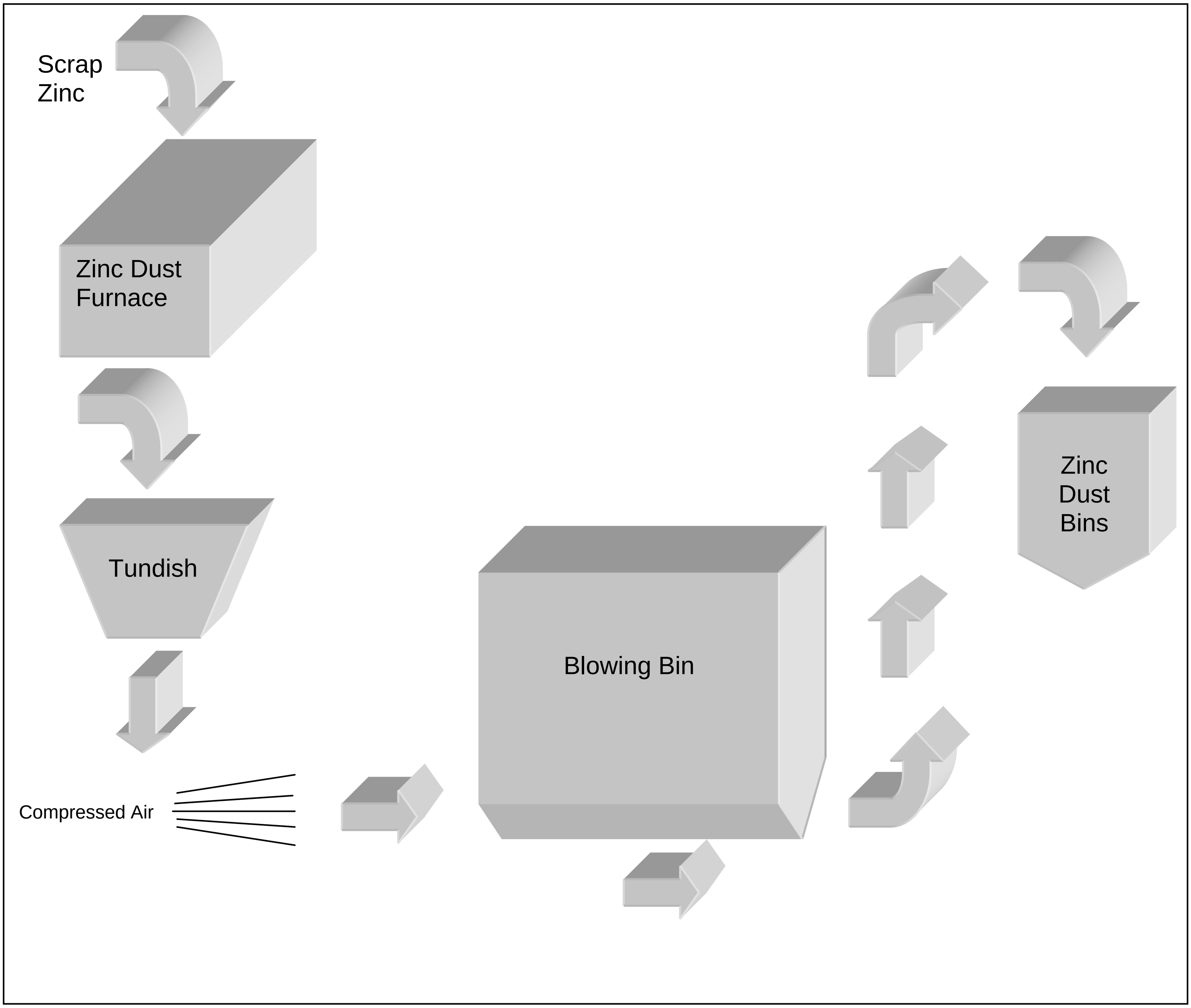
On 3 May 2002 an explosive type incident occurred at Zincor in Springs, South Africa, which led to a fatal accident. Given the history of relative benign behaviour of zinc powders under conditions conducive to dust explosions, it was decided to share the information of this incident with industry in an effort to prevent similar incidents. Therefore, the purpose of this paper is to describe the incident that occurred at Zincor, discuss the major findings, report on corrective actions, as well as publish the results of subsequent tests that were performed to determine the conditions under which zinc powder exhibits explosive characteristics.

1. THE PLANT

Zincor is a conventional roast-leach-electrowin producer of zinc metal. It produces approximately 115 000 ton per annum – primarily for the South African market. Zincor in its purification plant, uses locally produced zinc dust for a number of solution purification steps with the purpose of producing electrolyte, of a suitable quality, for the electrowinning step.

The zinc dust is produced in the Melt house operations. Zinc scrap and zinc bullion is melted in an electrically heated bath; the molten zinc flows into a tundish and the metal is atomized by a stream of dry, compressed air. The zinc dust is collected in a blowing bin with the finest fraction being collected in the furthest compartment. The zinc dust product is screened and blended before usage, whilst the air is filtered in a baghouse before release into the atmosphere. A schematic of the process is given below.

ZINC DUST PLANT
Figure 1



2. INCIDENT DESCRIPTION AND FINDINGS

On Friday 3 May 2002, an incident occurred at the Melt House Zinc Dust Blowing Bin, where a suspected explosion took place. One employee was fatally involved in this accident, due to burn wounds.

The initial incident investigation commenced immediately involving the standby personnel, eyewitnesses, management, the Safety, Health and Environment (SHE) Personnel, SHE and Union representatives and the fire team who extinguished the fire. The Inspector of Labour was also informed, as well as an Industrial Explosion Specialist from the CSIR (Council for Scientific and Industrial Research) who participated in the follow-up investigations.

Although none of the eyewitnesses actually saw what happened, according to all their statements they heard an explosive noise, saw a cloud of dust, saw the injured's overall on fire on top of the zinc dust blowing bin, and when he jumped down from the zinc dust blowing bin, they ran to assist him to extinguish the flames and render first aid until the ambulance arrived.

The fire team, on arrival, noticed that a large portion of the dust accumulated on the roof was burning with small blue flames. These flames were extinguished with relative ease as it was not burning with high intensity.

The investigation commenced subsequently and a number of important observations were made. Firstly the blowing bin showed no signs of structural damage inside or outside. Indeed there were very few signs of explosion or fire damage in the general area. Upon closer inspection it was found that the lid on top of the blowing bin roof was slightly out of position.

It was subsequently reported to the investigation team that the blowing bin was not in operation at the time of the incident, due to shift changeover, but that the compressed air used in the atomizing process was not closed off. The Zinc Dust Attendant had reportedly jumped onto the roof of the bin from an adjacent platform. Although one could not know for certain why this person had jumped onto the roof, it was also a practice, from time to time, to clean the accumulated dust on top of the roof, into the bin, through the lid in the roof by means of a spade. This was not a scheduled or required procedure for this person to have followed.

3. THE INVESTIGATION

3.1 Introduction and background

The phenomenon of dust explosions have been known and described since the 1700's. In the modern era there have been a number of serious dust explosion incidents worldwide, causing extensive damage, injury and loss of life. The increasing number of industries that handle or manufacture fine combustible powders has also increased the frequency of incidents in modern times.

Dust explosions occur when a sufficient amount of finely divided combustible material is suspended in an atmosphere that supports combustion in the presence of an ignition source of appropriate energy. Dust explosions can therefore occur when handling a seemingly harmless powder.

Most fine materials can actually participate in a dust explosion. Coal dust explosions are a well-known phenomenon in the coal mining industry. Most powders of a cellulosic nature such as grain dust, malt fines and wheat flour should be regarded as explosible. Sawdust and wood fines would have similar potential for dust explosions. Milk powder, spices, coffee and tea fines, sugar and powdered soup are examples of explosible dusts encountered in the food industry. Many organic pharmaceutical powders have the potential to explode violently under optimum conditions. Metal powders such as aluminium and manganese powder tend to explode most violently of all fine materials.

3.2 The dust explosion properties of zinc powder

Although it is known that a cloud of sufficiently fine zinc dust suspended in an atmosphere that would sustain combustion, could explode in the presence of an ignition source of appropriate energy, incidents involving zinc powder are not all that common. Table 1 is a summary of the laboratory data on zinc powder as found by Eckhoff[1]. The data suggest that zinc powders can explode quite violently, but that the concentration of airborne zinc dust required to initiate an explosion is very high. Many explosible dusts have a LEL (Lower Explosible Limit) of 30 to 60 g/m^3; but dusts with a LEL of 125 g/m^3 are significantly less likely to be involved in serious incidents. As an illustration of the quantity of airborne dust required to sustain an explosion, it is said that a person would be unable to see a glowing 25 W light bulb through a 2-meter thick layer of 40 g/m^3 of airborne coal dust[1]. The data also suggest that, once initiated, a zinc powder explosion can be relatively violent. The K_{max} value of a dust sample is dependant on the maximum rate of pressure rise generated by an explosion involving that particular sample. The following equation describes that relationship.

$$K_{\max} = \left[\frac{dP}{dt}\right]_{\max} .V^{\frac{1}{3}}$$

Where:

- K_{max} is the explosion index in bar.m/s
- $(dP/dt)_{max}$ is the maximum rate of pressure rise in bar/s
- V is the volume of the test vessel in m^3

The K_{max} (explosion index) value of 176 for zinc dust, as listed in Table 1, is probably higher than the K_{max} value for most types of coal. The low frequency of zinc powder explosion incidents is probably the result of the material's high LEL. In laymans terms: Zinc dust is unlikely to explode, but when it does, it will probably be quite a violent explosion.

Table 1: Ignitability and explosivity data for zinc and other metallic powders[(1)]

Sample description	**Median particle size (μm)**	**Lower Explosible Limit – LEL (g/m^3)**	**Max. explosion pressure – P_{max} (bar)**	**Explosion index – K_{max} (bar.m/s)**	**Minimum Ignition Temperature (MIT) for dust cloud (°C)**	**Minimum Ignition Temperature (MIT) for dust layer (°C)**
Zinc (from zinc coating)	19	-	6,0	85	800	>450
Zinc (from zinc coating)	21	250	6,8	93	790	>450
Zinc (dust from collector)	<10	250	6,7	125	570	440
Zinc (dust from collector)	10	125	7,3	176	-	-
Aluminium powder	22	30	11,5	1100	500	>450
Manganese (electrolytic)	16	-	6,3	157	330	285

The table also lists values for minimum ignition temperatures (MITs). Values for the ignition of either a dust cloud as well as a dust layer are listed. The reason why MIT's for layers are shown, is that a smouldering layer can also initiate a dust explosion. It should, however, be borne in mind that the topic of spontaneous combustion is complex and there are many other factors that would determine whether a material could initiate and sustain smouldering combustion. These factors could include the duration of exposure to elevated temperatures, the thickness of a particular dust layer, aeration within a dust layer or the presence of any contaminants. It can, however, be noted that the phenomenon of smouldering or spontaneous combustion is not unknown in processes dealing with metallic powders.

3.3 **Experimental Work**

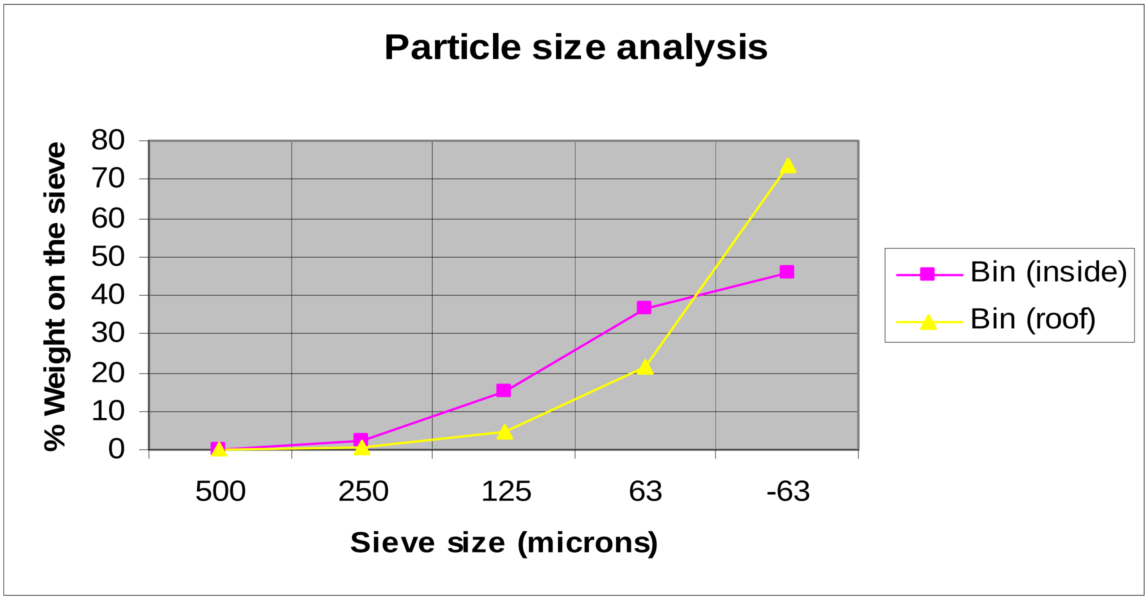
It is generally not good practice to apply literature data on dust explosion characteristics broadly, without performing tests on the dust actually found in the plant.

As part of the investigation into the incident at Zincor in 2002, two dust samples were tested at the CSIR. The one sample was the product powder from inside the blowing bin while the other sample was taken from a layer of dust that had randomly settled on the blowing bin roof over time. Chemically there was little difference between the samples. The roof and bin dust samples assayed 99,86% Zn and 99,93% Zn, respectively.

It was decided at the time to establish whether either of the two samples could participate in a dust explosion. The explosivity test procedure, as described in ISO 6184/1, requires that a series of tests be performed in the internationally recognised 20-litre test sphere (also known as the Siwek sphere). This particular procedure is designed to indicate whether a powder could potentially participate in a dust explosion. Tests are performed at various concentrations ranging from 30 g/m^3 to 2000 g/m^3. If at any time during the performance of a test series an explosion overpressure in excess of 0.2 bar is detected, the sample is deemed explosible. No conclusions regarding explosion intensity or explosion limits can be drawn based on the results of an explosibility test series; further test work would be required to establish those characteristics.

As part of the sample preparation process, the fraction of powder with particle size exceeding 500 μm was removed from the sample. Figure 2 reflects the particle size distribution of the two samples as they were tested. In a separate sizing initiative the D50 sizing of the roof and bin dust samples were measured at 57 and 181 micron, respectively.

Figure 2



The test results showed that the powder inside the blowing bin could not participate in a dust explosion, even when a sample was artificially manipulated to contain only particles less than 63 μm in size and re-tested. The sample taken from the roof of the blowing bin was, however, found to be able to participate in a dust explosion.

3.4 Potential ignition sources

The identification of a potential ignition source would always be a focus when performing an incident investigation. It is, however, often not possible to pinpoint an exact ignition source due to the destruction that usually follows an explosion incident or due to the nature of some ignition sources.

A few of the ignition sources that could typically be encountered in a process plant are discussed below:

- Welding, grinding, cutting or other "hot work" could all act as potential dust explosion ignition sources. The generation of mechanical sparks or hot embers during such activities could provide sufficient energy or temperature to ignite many types of powders. In this particular instance, no hot work was in progress at the time of and prior to the incident in that particular area. The likelihood of this type of ignition source having initiated this incident is therefore remote.

- Smoking and open flames could also act as ignition sources. Although a "No Smoking" policy should eliminate this type of ignition source to a large extent, one cannot always remove the human factor from the equation. In this instance, however, the deceased was known to be a non-smoker.

- An electrostatic discharge can also act as an ignition source for a dust explosion under certain conditions. Electrostatics is a complex subject, but it is generally accepted that very few types of discharges could release sufficient energy to initiate a metal powder explosion.

- Electrical equipment could also act as ignition sources, either due to the presence of electrical sparks or due to the generation of hot surfaces. In this instance, the only electrical equipment present in the direct vicinity of the explosion was a removable light assembly embedded into a lid on the roof of the blowing bin. The purpose of this assembly was to provide general lighting to the area on top of the blowing bin. It was found subsequent to the incident that this light was still functional; hence the likelihood of an electrical malfunction initiating a fire/explosion is small.

- Smouldering material can also act as an ignition source for a dust explosion, should such a pocket of smouldering material be disturbed for any reason. By studying the photographs taken immediately after the incident, one could observe a dust layer of substantial thickness on the blowing bin roof. One cannot eliminate the possibility that smouldering material could have been present within this layer. Such smouldering may have been initiated by prolonged exposure to the hot blowing bin roof and/or the light assembly mentioned above.

4. RECONSTRUCTION OF ACCIDENT

From the aforegoing it would appear that the most likely reconstruction of the accident is the following:

"The Zinc Dust Attendant decided to shovel settled dust, on the roof of the blowing bin, through the manhole into the bin itself. As this was not a scheduled procedure, no proper access to the roof was provided and the incumbent had to jump from an adjacent structure onto the roof of the blowing bin. This act created a cloud of dust that was exacerbated when he opened the manhole to shovel the accumulated dust into the bin. Opening the manhole released the compressed air being blown into the bin. The cloud of zinc dust that resulted on top of the blowing bin was subsequently ignited by a source that, most probably, could have been smouldering zinc dust which may have been the reason why the worker decided to address the housekeeping chore on the roof in the first place. Other ignition sources are not likely to have caused the explosion, but cannot be ignored as potential risks".

5. MEASURES TAKEN TO PREVENT RECURRENCES

At Zincor the following measures were introduced as a result of the accident:

- The plant was kept off-line until an electrical reticulation audit was successfully completed and the Inspector of Labour approved the start-up of the plant. The area was subsequently classified as Zone 2 in terms of SANS 0108. The lighting in the area was also upgraded.

- An outside contractor was employed to vacuum clean the entire plant and building of any settled dust. Regular plant cleanings are now, periodically, conducted. Housekeeping is more vigorously controlled from a zinc dust point-of-view.

- Proper access to the roof has been constructed, but the roof of the blowing bin is barricaded and is off-limit for any staff and access to the roof can only be carried out under appropriate supervision.

- The zinc dust plant has been declared a "No-Smoking area" and "hot maintenance work" can only be carried out under special supervision. The blowing bin section is electrically isolated during such maintenance.

- There is also an automatic "flame-out" detector on the pilot flame for the tundish. This ensures that the gas supply to the pilot flame is shut down in instances where the pilot flame has been extinguished.

- Standard operating procedures have been updated to include zinc dust to be re-classified as a "potential hazardous substance". Training has been implemented accordingly. Certain jobs now also require fireproofed overalls.

6. CONCLUSION

The tragic accident that occurred on 3 May 2002, at Zincor, has challenged the perception that zinc dust is a benign and innocuous material. Under specific circumstances zinc dust and powders can, most certainly, explode with violent consequences. It is hoped that this publication will assist in changing such views in the industry as a whole.

7. REFERENCES

1 Rolf K. Eckhoff, Dust Explosion in the Process Industry, Butterworth-Heinemann Ltd., Oxford, 1991