

## Dust Explosion Hazards in the Metal Handling and Processing Industry

Hazards are ever-present in the steel plant environment, and a heightened awareness and emphasis on safety is a necessary priority for our industry. This monthly column, coordinated by members of the AIST Safety & Health Technology Committee, focuses on procedures and practices to promote a safe working environment for everyone.

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Dust fires, flash fires and explosions are dangerous events in industry. They have led to loss of life, injury to personnel and destruction of equipment. The most common assumption made is that only organic matter is the cause of an explosion. It is true that most explosions involve organic material like sugar dust, grain dust, coal dust, wood dust or some type of fine chemical, polymer or pharmaceutical agent. What is not appreciated is that any substance, in a finely divided form, that can oxidize can be involved in a rapid combustion event creating a flash fire or explosion.

For example, aluminum can go to aluminum oxide, iron can go to iron oxide and copper can go to copper oxide. The list of metals that can participate in an oxidation reaction is very extensive. Some historical incidents include the aluminum dust explosion at Hayes Lemmerz, Huntington, Ind., USA, in 2003 with one person being killed and six injured, or the steel/iron dust and hydrogen explosion at Hoeganaes Corp. facility in Gallatin Tenn., USA, in 2011 killing five people and injuring three. In 2019 alone there were 29 metal dust fires and six metal dust explosions that injured 12 people globally.

It is very evident that metal dust fires and explosions are a serious problem. One of the best guidance documents to assist in mitigating these hazards is published by the National Fire Protection Association (NFPA) and called the NFPA 484: Combustible Metal Dust Standard. The guidance document has been accepted as industry best practice and in many jurisdictions enforceable since it has been adopted into local fire and building codes. These codes are only applicable if

dust/powder burns or can take part in an explosion/flash fire. So, the most common question asked: "Is my dust combustible?" The answer: "Maybe."

Dust combustibility and explosibility is not like vapor (e.g., gasoline) or gas (e.g., propane). Combustibility happens when one molecule of the fuel reacts with oxygen. For powders and dusts, the chemical composition of the sample, particle size distribution, particle shape and moisture content can greatly influence the severity of combustion and the ease of ignition. Therefore, tabulated or literature data on metal combustibility/explosibility may not exactly apply to the sample in the facility or process location and should only be used as a bellwether for reactivity. Actual safety-related decisions should be based solely on experimental data.

To that end, a good testing framework is essential. An example of a test framework is presented in Fig. 1. A detailed explanation of the schema can be found in *Methods in Chemical Process Safety, Volume 3: Dust Explosions* edited by Amyotte and Khan. What is being presented in Fig. 1 is a shortened overview of the methodology mentioned and is broken into four sequential stages.

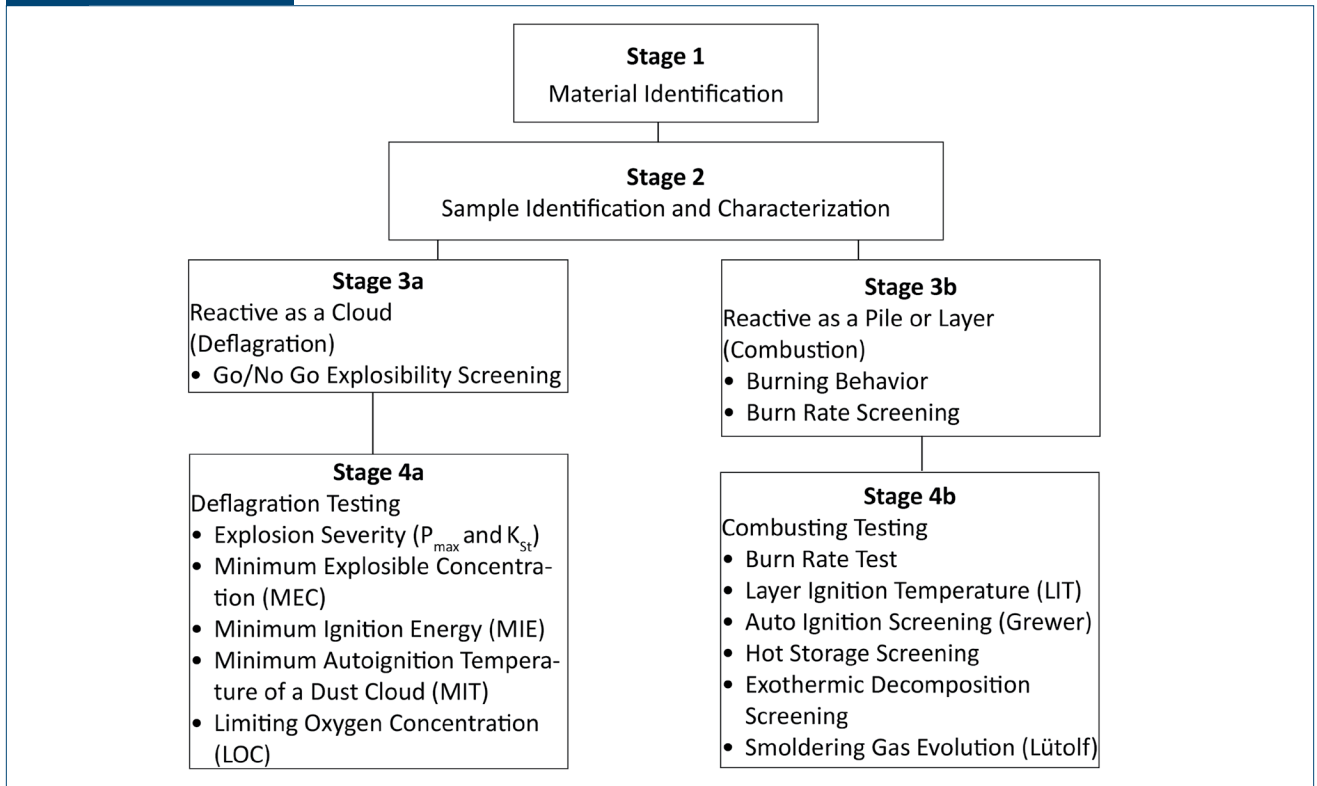
The first stage is to identify the material that is being dealt with. For example, is it aluminum fines or dust from a cutting operation, or stainless steel dust from a polishing or bead blasting operation, or iron dust from a laser cutting operation, or titanium dust from a 3D printing operation? The types of metal dust and the industrial operations that produce or handle them can number in the thousands. Especially taking into consideration the variation that may exist if the laser cutting

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Figure 1



Schema for combustible dust testing.

operation has variability in pad gas flow, thus affecting the makeup of the exhaust fumes and percent pure metal versus oxidized metal. Or, in the case of a bead blasting operation — how much paint resin or rust came off with the underlying steel.

So, once the material of concern is established, the next step is to move on to Stage 2 and assess where samples need to be taken from. For example, in the case of the laser cutting operation, the deposited metal droplets in the cutting machine will be different than the condensed weld fumes collected in the attached cyclone or cartridge filter box. Or, in a bead blasting operation, the dust in the cyclone would be different than the dust collected in the baghouse downstream. Each of those unique locations would warrant a sample for study.

After this step, the next segment of the analysis is Stage 3, which is broken into two parallel parts: a and b. Stage 3a explores the explosion/flash fire potential; technically called a deflagration. Stage 3b examines the burning or combustion potential of the sample. In Stage 3a, a deflagration screening test is conducted per ASTM E1226 “Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts” section 13 or an abridged ASTM E1515 “Standard Test Method for Minimum Explosible Concentration of

Combustible Dusts” test. If the sample demonstrates reactivity, then it can be considered a “combustible dust” and pose a potential deflagration. Protection systems and mitigation plans need to be put in place. In Stage 3b, the samples are being assessed for the propensity to sustain combustion in a layer or pile by performing either a burn rate screening test per “UN Manual of Tests and Criteria for Transportation of Dangerous Goods, Test N.1: Test Method for Readily Combustible Solids” or a burning behavior test per VDI 2263 Part 1. Both tests look at the propagation of flaming combustion along a layer of powder. If a propagation potential is observed, then the sample has the potential to spread a fire. So, if either Stage 3a or 3b returns positive, the material tested has a fire and/or a deflagration potential. Due to this potential hazard, it’s crucial to comply with NFPA 484, NFPA 652 and other related standards in the fire code.

One of these requirements is to perform a Dust Hazards Analysis (DHA). A DHA is a systematic review of a facility by a qualified person to assess if various dust/powder producing or handling operations has an explosion or fire hazard risk. However, if the DHA postulates that a credible dust fire/explosion hazard risk is present, the data in hand is not adequate to develop mitigation practices or design protection

systems. In order to determine that, Stage 4 testing would need to be completed. Again, as in Stage 3, the 3a path is to obtain data for deflagration characteristics and the 3b path is to obtain data for fire or bulk combustion characteristics.

The tests in Stage 4a should be conducted on each unique dust sample identified in the DHA. The most common test performed is the explosion severity test, which generates the values for  $K_{St}$  and  $P_{max}$  used in the design of explosion protection for equipment. Then the likelihood and sensitivity of ignition/propagation are assessed, establishing the minimum explosible concentration (MEC) for the sample. This is akin to the LEL of vapors and gases and represents the lowest suspended dust concentration that can propagate a deflagration. This value is important if the fuel load reduction will be used as a basis of explosion prevention. The next most common test is the minimum ignition energy (MIE) test, which can assess a sample's sensitivity to electrostatic sparks (if tested without inductance in the spark circuit) and to electrical sparks (if tested with inductance in the circuit). Once the sample's MIE is known, the environment can be screened for potential ignition sources. Electrostatic sparks below 30 mJ are very common in industry (e.g., sparks being generated by people) sparks from emptying drums or flexible intermediate bulk containers (FIBC) can reach 1,000 mJ. Electrical sparks from motors during start-up or load changes can reach 250 mJ with normal running load brush sparks about 25 mJ.

The minimum ignition temperature (MIT) of a dust cloud test evaluates the lowest temperature an enclosure would have to be at to auto ignite a sample. This value is also essential in establishing electrical "T" codes. Once the value is known, temperatures exceeding that value should be avoided in and around process equipment. Finally, there is the limiting oxygen concentration (LOC), which establishes the lowest oxygen level needed to propagate a deflagration. This value is used in conjunction with NFPA 69 to establish argon or nitrogen levels that will prevent a deflagration in process equipment. If inert gas padding is to be used for explosion protection for the metal dust sample, make sure that the gas does not react with the material. Some metals react with nitrogen and therefore argon is a better choice. Please note that this type of inerting, if not executed properly, may pose an asphyxiation hazard to fellow employees.

Stage 4b is used by many in the metal dust handling and processing industries to look for fire and self-heating hazards in their facilities. The burn rate test uses a more elaborate procedure from UN Method Test N.1 and the speed of propagation of combustion of the metal pile can be used to gauge the relative rapidity of combustion and using this information, one can establish fire protection and evacuation

requirements for their facility. Of the tests remaining in Stage 4b, the layer ignition temperature (LIT) and the hot storage screening test are the most common. The LIT test establishes the safe limit surface temperature on which the metal powder/dust can sit. By keeping layer temperatures below this level, for example the top of an oven, heated pipe or motor covering, ignitions can be avoided. Additionally, the LIT and MIT will be needed to select the appropriate "T" code for the electrical equipment.

The auto ignition screening, hot storage screening and exothermic decomposition screening are slight variations of a similar methodology which holds the powder/dust sample as a bulk article (cube or cylinder) in a heated enclosure and then observes for self-heating/smoldering of the material leading to full combustion. These methods are used primarily for assessing combustion hazard risks in heated, enclosed spaces like ovens and furnaces, but they can generally apply to any elevated temperature enclosure. Once the tendency to self-heat has been determined, a rigorous analysis will need to be conducted to establish an ignition temperature and volume correlation. The final test, the Lütolf oven test, is not that common for metals as it looks for the generation of offgases as the sample is heated. Metals generally won't offgas but if metals are mixed with organics, like in bead blasting painted metal surfaces, this test should be conducted to establish the potential of flammable gas hazards in the process and the likelihood of more energetic gas-dust hybrid clouds being present.

With this data in hand, one can establish a more complete picture of a powder/dust sample's combustibility characteristics. The schema presented in Fig. 1 is one acceptable analysis procedure but it by no means is the only protocol for this work. As such, not all of these tests may be necessary for a particular process or facility; for that matter, additional data from tests not covered in this discussion may have greater value, like the test for pyrophoricity or the test for flammable gas generation when a sample is wet. Ultimately, it is essential to have a fire and explosion prevention plan for processes and facilities if combustible/deflagrable metal powder or dusts are being handled. And, given the nature of combustion for solid particles, extracting values from historic data tables may not reflect the true hazard potential of the specific material being handled or processed at each facility. ♦