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FIRES AND EXPLOSIONS ASSOCIATED WITH ALUMINUM DUST FROM FINISHING OPERATIONS

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Summary

Aluminum dust produced by finishing operations is an explosive dust which can burn or explode if not properly controlled. This report reviews a number of fires and explosions occurring in New Hampshire that involved aluminum dust produced by grinding, polishing and buffing. Improper design of dust collection systems, performing maintenance activities while the system is on, and processing dissimilar metals contributed to these losses. The hazards of collection of these dusts through ventilation systems, various standards and general methods used to control these risks are discussed.

Introduction

The element aluminum is the most abundant metal found in the crust of the earth. It has numerous uses in society and can be found in many products. The manufacturing of products made from aluminum often involves grinding, sawing, buffing or polishing to impart a finish to the product. Dust generated from these operations is often controlled by a ventilation system that consists of a hood for dust capture, ducts to transport the dust away from the operation and collection devices to concentrate the dust for ultimate disposal. Aluminum dust created from such operations has certain characteristics which make it potentially dangerous. One such attribute is its ability to rapidly oxidize creating a combustion hazard. Since the particles created from grinding, sawing, buffing and polishing are small in size and easily form dust clouds, there is a further danger of dust explosion.

As early as 1918 the United States Bureau of Mines has reviewed and disseminated information concerning the flammability hazards of aluminum dust [1]. This was seen as a need following several disastrous dust explosions involving this metal. The Bureau recommended precautions including ventilating and grounding machinery which produces aluminum dusts. Since then, the

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Bureau of Mines has conducted explosibility tests on aluminum and other metal powders [2]. In these tests characteristics such as minimum explosion concentration, explosion pressure and rate of pressure rise were determined by use of the Hartmann apparatus [3]. Dust used for these tests was first screened through a number of sieves to determine average particle diameter. The test data developed by the Bureau of Mines for these samples included samples with average particle diameters ranging from 10 to 100 microns. The tests in the Hartmann apparatus found a wide range of results for aluminum dusts dependent on a number of factors. Characteristics such as particle diameter were found to play an important part in determining the explosibility of aluminum. Smaller particles have a larger surface area available for oxidation per unit weight and also represent a smaller heat sink. It was shown that as the particle diameter decreased, the minimum energy needed for ignition decreased and the rate of pressure rise increased. The minimum explosive airborne concentrations for dusts was also found to be dependent on average particle diameter. Additionally, mixing aluminum with an inert material was found to lower both the rate of pressure rise and the maximum pressure obtained. Ignition was prevented in samples by adding up to 90% inert materials. An empirical explosibility index was developed by comparing the ignition sensitivity and explosion severity of the sample results to those found for Pittsburgh seam coal dust. Under these test conditions the aluminum dust had a maximum rate of pressure rise as great as 20,000 psi/s (1380 bar/s) or more than eight times that of coal. Aluminum dust required less spark energy for ignition and was found to have a lower minimum explosive airborne concentration than that of coal. The maximum explosion pressure was found to be on the order of 100 psi (6.9 bar). Aluminum was thus given an adjective explosion hazard rating of "severe" [2]. More recently it has shown that the values obtained also depend of the size of the testing apparatus. Currently the 20 l sphere or the 1 m^3 vessel are used for the testing of combustible dusts.

Since 1955 the National Fire Protection Association (NFPA) has recommended that aluminum dust from processing or finishing operations such as buffing, grinding, sawing and polishing be collected with certain safe guards. Revised periodically, these standards include the prohibition of dry collection devices when located inside buildings. The standard also requires dust transport velocities of greater than 4500 ft/min (1372 m/min) to insure the complete conveyance of the dust and requires the elimination of possible sources of ignition [4]. Despite these and other relevant long standing recommendations from NFPA, aluminum dust fires and explosions continue to occur with regular frequency.

Case studies

Three investigations that followed aluminum dust fires or explosions were reviewed. While there are a number of factors which contributed to each one of these incidents, we titled them by the major suspected source or activity responsible for the incident. The first was caused by maintenance activities (welding) which took place while excessive dust was in the area. The second appeared to be caused by the processing of dissimilar metals while the third involved the use of improper dust collecting systems.

Maintenance activities

A facility which was involved in the production of epoxy laminates consisting of aluminum and fiberglass sheets was damaged by an aluminum dust fire during maintenance repairs. An automatic wide face metal sheet finishing machine was used which could process both sides of an aluminum sheet at the same time. The dust collection system from this machine consisted of duct work, and a cyclone collector followed by fabric filter bags. The dust collectors were located in a room separate from the polishing work area. In the dust collecting room housekeeping efforts were lacking as there was dust build-up on the eaves, rafters, floor and in exposed fiberglass insulation in both rooms. The fire began in the eaves during an acetylene torch cutting repair operation adjacent to the dust collection room. These repairs were conducted while the process equipment was still in active production. The incident was further exacerbated during attempts to put the smoldering fire out by the use of improper fire extinguishers. An ABC dry type fire extinguisher disturbed the dust and fed flames throughout the area. The fire spread to the insulation and underside of the roof in the dust collection room, but fortunately did not involve the filter bags. Samples taken from the dust collection devices indicated that the dust particles were made up of at least 80% aluminum and approximately 70% by weight had a diameter less than 75 microns.

Processing dissimilar metals

Small fires in an aluminum system can often serve as a warning that larger incidents are possible. A manufacturer used a wide belt grinding (sanding) machine to sand off both sides of parts that would subsequently be used in the housing of electrical equipment. Flat aluminum or steel pieces were hand fed into one end of the sander and removed at the other. The dust collection system consisted of three dust take off points; two were flex ducts and one was a sheet metal duct. One of the flex ducts joined the sheet metal duct within a few feet of the sander while the other terminated at the duct in a plenum at the outside wall approximately 20 ft (6 m) from the unit. Located outside was a small 5 hp dry cyclone followed by zipper type cloth filter bags. This operation had been running approximately three years. While previous small fires had occurred in this department, the incidents had been contained and limited to the sanding area and the cyclone collection barrel. On the day of the explosion the unit was processing steel parts. The operator noticed a glow within the sanding unit. While the unit was still on, he attempted to knock the glowing mass out of the machine and noticed the flex duct smoking. At that point there was an explosion causing burns and hospitalization of a worker standing at the feed end of the unit. The fire and explosion also involved the collection barrel below the cyclone and the filters which burned away. A dust sample from the inside of one of the ducts to this machine indicated 18% was less than 150 microns in size. The composition was approximately 50% aluminum and 30% iron.

Improper dust collection system

A firm involved in finishing molding strips had a number of incidents involving aluminum within a two year period. The accidents were related to a poorly functioning and improperly designed dust collection system. The manufacturer used automated brushing and buffing machines to impart a finish to extruded aluminum strips. Each piece was first brushed using abrasive wheels and then buffed with a cloth buffing wheel and buffing compound. While both types of machines were ventilated by local exhaust hoods, visible dust was emitted at the machines allowing some accumulation outside the duct work.

At the time of the first reported accident there were four 30 hp dust collectors located indoors in the work area. Each unit consisted of a cyclone followed by a set of eight bag filters. Three maintenance workers were hospitalized when an ungrounded duct they were removing exploded and burned. Approximately seven months later one of the fabric collectors caught fire and burned, this time without causing injury to personnel. The two dust collectors associated with the brushing operation were then relocated to a dedicated room separate from the work area by a concrete block wall. The cyclone-filter bag units discharged into this room and the concrete block wall had louvered openings to allow cleaned air to be recirculated back into the work area, thus minimizing heat loss. At the opposite side of the dust collection room was a curtain wall intended to function as a blowout wall for explosion venting. This wall was located on the exterior of the building. Approximately 60 ft (18 m) of duct connected six brushing machines to each of the two collectors. A sample of collected dust from the brushing process was found to be comprised of nearly 85% aluminum. A third accident occurred in which six workers were hospitalized when one of the brushing dust collectors exploded. The exact cause of the ignition was not determined, however it was speculated that the use of a hand held dressing stone could have been the cause. The force of the blast blew out the weak wall, sheared bolts off the louvers, and shifted the top row of concrete blocks in the dust collector room. The blast propagated back through the collection system where it knocked duct work to the floor and injured the workers. Immediately after the explosion an unaffected parallel duct which was connected to the same machines at a different take off point was examined. It was found to contain 1–3 in. of dust build-up within it's length indicating insufficient transport velocity.

Additional reports

Illig [5] has also described examples of the explosion potential of fines generated from normal finishing operations. In the four detailed accidents there were thirteen fatalities and two serious injuries. Two of the cases involved aluminum foundries and were initiated after sparks were carried into a ventilation system. The third fire also involved a foundry where a significant amount of dust had built up on ledges and equipment surfaces over the years. When firemen responded to a blaze which had started, they used high pressure hoses and a series of explosions resulted. The fourth case involved a dust collecting device consisting of a filter, exhaust fan and a partially filled drum of water. The explosion presumably was caused by hydrogen gas generated by the reaction of water and the partly covered aluminum waste.

Discussion

There are two strategies used to minimize the risks of aluminum dust fires and explosions. The first consists of reducing the chance (frequency) of ignition through strict ventilation design and elimination of sources of ignition. The second strategy involves minimizing the extent of the damage (the consequence) once a fire occurs. Both concepts need to be incorporated into the design of ventilation systems that handle aluminum dust.

Frequency

Reducing the chance of fires and explosions for any combustible material requires the elimination of fuel, air or the ignition source. Inerting the air or the fuel to reduce the hazard during collection has proved difficult. Studies using the Hartmann apparatus have shown that prevention of aluminum dust explosions requires inerting the oxygen levels down to 2% when using carbon dioxide and 7% when using nitrogen [6]. Other tests attempted to prevent aluminum dust explosions by mixing the sample with an inert dust. It was found that up to 90% inert dust was often needed [2]. Design controls have therefore concentrated on reducing ignition sources and the amount of available fuel. An NFPA standard [4] requires, for example, that duct transport velocities be greater than 4500 ft/min (1372 m/min) to prevent dust from settling in the ducts and to insure reentrainment of any particles left in the system when it is turned on.

The standard further prohibits the use of filter collecting devices when used with the processing or finishing of aluminum. Recently the Technical Committee on Metal Dusts of the NFPA has proposed for adoption an amendment to NFPA-65 which would allow the use of fabric or filter media type collectors. The amendment requires that synthetic fabrics which accumulate high static charges not be used [7]. Unfortunately, filters often preceded by a cyclone, concentrates the fine dust in a manner that can be easily ignited and thus filters should be avoided. As indicated by the fires and explosions presented in this paper, the source of ignition came from conditions outside the collecting devices. In two of the cases the sparks were drawn into the dust collection system and filters resulting in loss and injury.

Wet collecting devices are permitted by the NFPA standard and recommended by the Aluminum Federation [8] to collect aluminum dust. Unlike dry collectors, they may be located indoors. Wet collectors must be used with certain safe guards to prevent the accumulation of hydrogen gas in the system. Sludge from the collector must be removed and disposed of on a daily basis. Recommended design and practice include the use of vents in the upper parts of the duct work as well as the collector and sump. The fan should be operated for a period prior to and after the dust producing operation to assure that the system is purged of dust. Additionally, a low liquid safety control is usually recommended to prevent operation without sufficient water [4,9,10].

As can be seen from the case studies, strict control of maintenance activities involving welding and cutting is important as is good housekeeping of fugitive dusts. Elimination of sources of ignition also includes using separate dust collection systems when incompatible dusts, such as steel and aluminum, are generated in the same facility. Smoking should obviously not be allowed in areas where aluminum dust is produced or handled.

Consequence

Even with the design controls already referenced, fires and explosions should be anticipated and planned for. Use of explosion relief vents on ducts and dust collection devices is necessary to reduce the maximum overpressure to a safe level during an explosion. As a general rule the vent size should be as large as feasible and the dust collector housing as strong and small as practicable. Vents should be located as close as possible to the anticipated point of ignition. Vent covers must be kept to a minimum mass per unit area in order to maintain a fast opening time. Specific design guidelines for the proper size and placement in ventilation systems based on experimental tests and experience are given by a number of sources [11–16]. Damage to the building and injuries to personnel can be further minimized by placement of dry dust collectors both out of doors and in safe locations.

Limiting the amount of fuel available for combustion further reduces the consequence of a fire or explosion. Codes recommend that duct work be as short as possible and that collected dust be disposed of on a daily basis [4].

The use of liquid or gas extinguishing systems in aluminum dust fire control situations have certain disadvantages. These systems require a certain amount of time to detect an incipient fire. Such time may not be available for aluminum fires. In addition, attempts to build up sufficient concentration of the extinguishing agent may be hampered by opened explosion vents and by a continuing air flow caused by the fan [17]. Finally, the use of water or other vaporizing liquids or gases as extinguishing agents is contraindicated due to dislodgement of dust and production of hydrogen gas or other explosive compounds.

Additional controls

Alternative or additional controls for combustible dusts have also been recommended which may find future use with the collection of aluminum dust. Spark traps that employ a settling chamber use a low air flow where large sparks can settle out prior to their entry into more vulnerable dust collection devices [18,19]. The use of abort and backblast dampers in ducts has been suggested for collection of certain combustible dusts. Abort dampers can block a duct and redirect sparks which have been observed by an infrared detector. Such a device would be used in a system which operates under positive pressure [17]. This would represent a situation not currently recommended by NFPA for aluminum dust because it requires placement of the fan in the dust laden air stream. Backblast dampers are designed to prevent an explosion from propagating back through the duct work. This would be useful in protecting the upstream operators and assuring overpressures are relieved through designed explosion vents [11,17,20].

Conclusions

As these case reports indicate, the collection of aluminum dust from grinding, buffing and polishing can present significant hazards when existing codes and safe guards are ignored. Fortunately, there are means available to minimize both the frequency and the consequence of aluminum dust fires through careful design and operation of ventilation systems. This includes competent engineering design, proper location of dust collectors, and attention to housekeeping. All potential ignition sources must be eliminated such as prohibiting the processing of incompatible materials and aluminum in the same system, grounding of metal equipment, and performing cutting and welding operations only during shut down after the area has been thoroughly cleaned and inspected. The appropriate consensus or government codes should be adhered to.

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Disclaimer

The opinions, findings and conclusions presented by the authors are not necessarily those of the Occupational Safety and Health Administration.

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