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Guidelines about safe handling of the new powders

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Content

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1. Introduction

Using metal powders, lasers, etc introduce several types of risks for personal injury. It is important to understand the nature of the risks and the processes were the risks occur. Handling large quantities of metal powder is not a dangerous undertaking if these risks are accounted for. Without going into too much detail it can be stated that a number of factors must coincide in order to create a dangerous situation, i.e. for a dust explosion to occur, the dust must exhibit a certain reactivity, it must be mixed with air (oxidant) at a certain concentration and an igniting event must occur. If any of these factors are avoided there will be no explosion. On the other hand, if some of these factors are allowed to develop uncontrolled (unseen) a dangerous situation can occur without anyone noticing. In this report we try to point out ways to avoid that this can happen. Guidelines on how to organise the workplace for a safe work environment can be found in standard referenced as number 1 in this text.

1.1. Background

The risks of using metal powders can be divided into two groups according to their root cause, mainly fire/explosion and different types of toxicology. Dust fires or explosion usually occur when dust is either accidentally released or is allowed to accumulate over time to reach too high levels. Toxicological injury usually occurs when workers are exposed to dust over a prolonged length of time. This can happen either by ignorance or by relaxed safety standards were workers do not use the protective equipment available. This usually happens because the equipment is considered too difficult, too heavy, too uncomfortable or too time consuming to use. In either cases a proper risk assessment should be performed and changes in the workplace and associated procedures should be performed. The present report attempts to outline some of the risks and points to some simple mitigations that can be implemented.

1.2. Scope

In the project two steel powders (S-type and T-type) have been developed. Furthermore, an Al-alloy powder has been used as reference in one of the cases. The hazards and recommendations proposed here will be limited to these powders. However, in most cases the recommendations

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are generic to all metal powders. An important aspect of metal powder is the size of the metal particles. The size ranges covered here are typical of size ranges required by the Laser Powder Bed Fusion (LPBF) process (10-53 μm) and for Direct Energy Deposition (DED) process 53-150 μm.

2. Nomenclature and concepts

Certificate of Analysis

The powder producer issues a certificate to show that the powder lot conforms to the specification.

Fines, dust

Fines are the powder particles that are smaller than the specification. For LPBF it means smaller than 10-15 μm, while for DED slightly larger. Very small powder can be airborne and is very susceptible to electrostatic forces. This means that these particles can be transported by airflow. In most cases this is good since it means that we can remove airborne condensated metal vapour before it drops down into the powder bed during the laser scanning in a LPBF process. However, some condensate will inevitably fall into the powder bed and get stuck there.

Particle size

Powder size is a concept that is not rigorously defined. Basically, two ways of measuring particle size are available: Sieve analysis where the powder is sieved on sieve cloths with more and more narrow openings. A typical sieve fraction for a LPBF powder is 20-53 μm and a typical particle size specification is that 2% of powder is allowed to be smaller than 20 μm, but 0% is allowed to be smaller than 15 μm. On the larger side 2% is allowed to be larger than 53 μm, but 0% is allowed over 63 μm.

The second particle size measurement method can be divided into two subgroups, laser light diffraction and laser particle image analysis, however, in this context they are similar. They measure the size of a large number of individual particles. The result is typically delivered as a particle size diagram, where d10, d50 and d90 can be derived. D10 is the largest particle of the 10% smallest particles. D50 is the size of the median particle and d90 is the size of the largest of the 90% smallest particles. Unfortunately, measurements from different brands of laser particle size measurements cannot be compared to each other. It is also not possible to get a rigorous comparison to the sieve analysis.

One way to describe powder size is by sieve fractions.

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Another way to describe the particle size is by using d10, d50 and d90. These measurements try to describe the particles size distribution of the powder lot.

Powder Lot, powder batch

All powder belonging to the same identified manufacturing lot (or batch). Each lot gets an ID number and a Certificate of Analysis by the powder producer.

Safety data sheet

A safety data sheet (SDS) is a document that lists information relating to occupational safety and health for the use of powder feedstock. SDS information may include instructions for the safe use and potential hazards associated with the powder, along with spill-handling procedures. The SDS format is internationally regulated.

The SDS is intended for use in the value chain and not by the end consumer. There is also a duty to properly label substances (powder) on the basis of physico-chemical, health, or environmental risk. The SDS is specific to each product and is supplied to the customer either as part of the shipment or electronically. Typically, it can be attached to packing lists or to a Certificate of Analysis.

Specification

The powder producer or powder producer together with the customer (for customer specific products) defines a specification for the product. All analyses that should be performed on the powder lot should be listed here and their respective measurement procedure should be identified. For most variables a maximum and a minimum value should be defined in order to be acceptable for the customer. The product for which the specification is not valid is identified by an item no or an article no.

3. Identified Hazards

Dust and fine powder can represent a serious health, environmental and safety hazard. Airborne dust is not always visible to the naked eye and it may enter the body by ingestion or skin absorption. The most vulnerable hazards associated with dust, however, are inhalation and combustion. The hazards identified here can cause bodily harm if not properly contained. They can also cause equipment to break down with a high cost as end-result. Mechanisms or phenomena that are “only” harmful to powder or part quality are not covered by this report.

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3.1. Dust explosions or fires

Dust is defined as "small solid particles, conventionally taken as those particles below 75 μm in diameter, which settle out under their own weight, but which may remain suspended for some time" according to the ISO 4225:2020 standard [2].

There are five conditions that must be reached for a dust explosion to occur:

1. A combustible dust
2. A dust dispersed in the air at a certain concentration
3. An oxidant present (usually atmospheric oxygen)
4. An ignition event
5. A confined volume – a building can be an enclosure

If any of these conditions are not met there will not be an explosion. Most metal powders are definitely oxidizable, in fact all steel powders have a thin oxide layer on the surface. This layer limits the risk for oxidation at the surface but does not make the powder immune to further oxidation. However, the size of the particles come in a as an important factor: 4 μm steel particles needs only about half the concentration in air in order to explode compared to about ten times larger particles. The powder size used for LPBF process is in the range 15-45 μm. Naturally, these factors are different for different elements. Easily oxidizable elements such as Al, Ti and Zr require less concentration in air in order to reach combustible levels compared to e.g. steel, while e.g. nickel is virtually immune. In the present context an Al-alloy powder is used as reference and the minimum concentration is one quarter compared to Iron-based powder for a particle size near 40 μm. In [3] many specific powders are listed and their properties with regards to dust explosions are discussed. Many specific safety considerations for additive manufacturing are discussed in [4].

Further reading on this subject can be found in [5-7].

In the Safety Data Sheet (SDS) that is supplied with the powder, the risk for dust explosion or fire is identified. It also identifies which extinguishing media should be used and provides advice for firefighting.

3.2. Health effects

Dust can create adverse health effects by inhalation into the lungs if the particles are small enough, by ingestion and or by skin contact. The health effect depends strongly on the chemical composition and type of compounds included in the dust or powder. In this context the powder is

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iron based metal with some alloying elements, which means that powder is not toxic for skin or ingestion. The main risk to human health presented by “iron” dust is related to the concentration of dust in the air acting as a nuisance dust. The higher the concentration of dust the greater the risk of irritation to the respiratory system and mechanical irritation of the eyes.

3.3. Environmental Hazards

The effect of the iron-based metal powder on the environment is moderate. The iron-based powder is not considered to be toxic and the solubility of iron in water is very low.

Iron is found in the form of hydroxides in the environment. The stabilized form (long term) is iron oxides.

The iron-based metal powder is not classified as hazardous waste according to directive 2008/98/EC. Furthermore, carefully emptied packaging can be incinerated (Directive 94/62/EC). Packaging that cannot be carefully cleaned should be disposed as special waste according to local and national regulations.

3.4. Safety Data Sheets (SDS)

Safety data sheets (SDS) provide a useful organisation of basic risks associated with a powder and should be a first point to look for a minimum hazard assessment. This information should be the starting point for safe handling of metal powder. These risks and mitigation strategies are discussed in some detail in [4]. For further details related to the general content of an SDS, please check the Annex to the regulation of REACH at

https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32015R0830&from=EN

Specific Safety Data Sheets for the developed alloys have not been created yet, but alloys very similar in composition and form are available. The S-type reference alloy (X-4130) have virtually the same chemical composition and particle shape as the developed material. The developed T-type powder contains slightly more chromium compared to the reference material (AISI H13), but this small difference will not cause any practical change in the SDS. The reason for this is that when the chemical composition interval for the alloys is listed, it is made so wide that it will include any reasonable variations in the alloy composition. In this case it means that the SDS for the H13 alloy and the T-type steel will be identical. The SDS for the S-type steel powder is included as Appendix 1 and the SDS for the T-type steel powder is included as Appendix 2.

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4. Process specific considerations

4.1. Storage and handling of powder feedstock

Powder must always be stored in a clean and dry environment at near ambient temperature. Temperature variations can lead to condensation of water on the powder, affecting the quality of the prints negatively.

It is also important that it is possible to clean the storage room used. If powder containers are opened in the room a diffuse spreading of airborne particles will take place. The amount may be small and not noticeable by the naked eye, but over time it may settle on surfaces that are not regularly cleaned (dusted).

It is recommended that point ventilation is used when containers are opened and that there is a general good ventilation in rooms were powder is open to air. The ventilation system itself should be designed to avoid settling of powder in the transportation channels and that filters are of appropriate type and proper maintenance is ensured.

Transferring of powder from one container to another should preferably be performed in a closed system. Free-fall of powder open to the room air should be avoided. If it is necessary, a point ventilation system should be used, or the work should be performed using a fume hood.

Re-using powder is a normal procedure in additive manufacturing and it includes sieving all powder. These processes will inevitably create diffuse spread of very fine powder. The first counter measure is a closed system and point ventilation at the equipment. It is also important to have procedures so that any spillage of powder on the floor (risk of slipping) is quickly taken care of. Maintenance of sieves and other parts should be performed in fume hoods to minimize possible exposure.

Keep the workplace clean! Historically, the diffuse accumulation of dust has been the greatest source of combustible particles in most dust explosions/fires.

4.2. AM Processes

It is required to follow the specific actions according to the manuals and training provided by the individual equipment manufacturers, independent of additive manufacturing technique used (e.g. Laser Powder Bed Fusion (LPBF), Direct Energy Deposition (DED), …).

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Re-using powder

In the LPBF build chamber only a relatively small part of the volume will be taken up by the built parts. The remaining volume will be support structures or powder that is situated between parts. Furthermore, when feeding powder, it is necessary to feed more powder than what is required for each layer, sometimes only half the amount is used for the new layer. The remainder is collected in a container and can be mixed with the powder from the build plate after the build is completed. This powder will contain not only the powder originally added, but also spatters and condensate that has not reached the filters. This powder will be sieved for oversize particles (large spatters) and the remainder will be used again, either as is or by diluting it with virgin powder. If the powder is diluted with virgin powder, mixing is required in order not to have variations in spreading behaviour.

The support structures can be scrapped and possibly be re-used in the powder production process.

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5. Relevant standards and guidelines

In this section a selection of relevant standards and other documents are listed.

List of standards and other texts referenced in this report

Ref	Source
1	ISO 45001, **Occupational health and safety management systems – Requirements with guidance for use**
2	ISO 4225:2020, **Air quality – general aspects – vocabulary**
3	NFPA 484, **Standard for Combustible Metals, Metal Powders, and Metal Dusts**, 2002 Edition
4	ASM Handbook, Volume 24, Additive Manufacturing Processes, D. Bourell, W. Frazier, H. Kuhn, M. Seifi, editors, DOI 10.31399/asm.hb.v24.a0006544, **Safety in Handling of Metal Powders**,
5	DIRECTIVE 2014/34/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2014 on the harmonization of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres (recast)
6	**Safety and Environmental Aspects,** ASM Handbook, Volume 7, Powder Metallurgy, P. Samal and J. Newkirk, editors, DOI: 10.31399/asm.hb.v07.a0006075
7	**Safety Instructions for Handling and Processing Aluminium Powder**, Gesamtverband der Aluminiumindustrie e.V., 2007

Selected standards related to dust explosion hazards covered by the Directive 2014/34/EU not specifically mentioned in the text

Standard	Title
EN 1755:2015	Industrial Trucks - Safety requirements and verification - Supplementary requirements for operation in potentially explosive atmospheres
EN 1834-2:2000	Reciprocating internal combustion engines - Safety requirements for design and construction of engines for use in potentially explosive atmospheres - Part 2: Group I engines for use in underground workings susceptible to firedamp and/or combustible dust
EN 1834-3:2000	Reciprocating internal combustion engines - Safety requirements for design and construction of engines for use in potentially explosive atmospheres - Part 3: Group II engines for use in flammable dust atmospheres
EN 13821:2002	Potentially explosive atmospheres - Explosion prevention and protection - Determination of minimum ignition energy of dust/air mixtures
EN 14034-1:2004+A1:2011	Determination of explosion characteristics of dust clouds - Part 1: Determination of the maximum explosion pressure pmax of dust clouds
EN 14034-2:2006+A1:2011	Determination of explosion characteristics of dust clouds - Part 2: Determination of the maximum rate of explosion pressure rise (dp/dt)max of dust clouds
EN 14034-3:2006+A1:2011	Determination of explosion characteristics of dust clouds - Part 3: Determination of the lower explosion limit LEL of dust clouds
EN 14034-4:2004+A1:2011	Determination of explosion characteristics of dust clouds - Part 4: Determination of the limiting oxygen concentration LOC of dust clouds
EN 14491:2012	Dust explosion venting protective systems
EN 15188:2007	Determination of the spontaneous ignition behaviour of dust accumulations
EN 17077:2018	Determination of burning behaviour of dust layers
EN ISO/IEC 80079-20-2:2016,	Explosive atmospheres - Part 20-2: Material characteristics - Combustible dusts test methods (ISO/IEC 80079-20-2:2016)
EN 50281-2-1:1998	Electrical apparatus for use in the presence of combustible dust - Part 2-1: Test methods - Methods for determining the minimum ignition temperatures of dust
EN 50303:2000	Group I, Category M1 equipment intended to remain functional in atmospheres endangered by firedamp and/or coal dust
EN 60079-31:2009	Explosive atmospheres - Part 31: Equipment dust ignition protection by enclosure "t"
EN 60079-31:2014	Explosive atmospheres - Part 31: Equipment dust ignition protection by enclosure "t"
EN 61241-4:2006	Electrical apparatus for use in the presence of combustible dust - Part 4: Type of protection "pD"

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