Safe utilization of Additive Machines: a guide for end-users

E. Annacondia
AITA-ASSOCIAZIONE ITALIANA TECNOLOGIE ADDITIVE, Cinisello Balsamo, Milano, Italy

L. Di Donato
INAIL, Rome, Italy

ABSTRACT: This paper presents activities performed by INAIL and AITA-ASSOCIAZIONE ITALIANA TECNOLOGIE ADDITIVE to support industrialists, end-users and all the people involved in the field of the safety of machinery in managing additive technologies applications. The main focus is to describe the basic concepts for safety of machines operating with Powder Bed Fusion or Powder Bed Sintering processes. As a result of the above mentioned activities, a technical report (in Italian and English languages is at the final draft status, next to the printing activities and will be published soon. It aims to represent a reference for manufacturers, employers and operators about duties related to safety of Additive Technology machines in Italy, but it also represents an analysis of main hazards and potential risks.

1 INTRODUCTION

In the last few years, Additive Technologies are becoming increasingly diffused, both for hobbyist and industrial application.

Relating to hobbyist level (home-made and fab-labs), the diffusion of 3D printers has increased the popularity of additive processes, allowing the realization of a number of self-made products and creating the concept of "digital craftman".

At industrial level, Additive Manufacturing (in the following, AM) has been used since the end of the Eighties, when its main application was the so-called Rapid Prototyping, usually based on stereolithographic processes. It was (and is) used to check the quality of design at geometrical and aesthetical level, while mechanical performances are not taken into account (because of the use of polymeric materials with poor strength).

Conversely, in the last few years, a number of additive processes are gaining popularity within some industrial sectors, because of their ability to realize functional parts (i.e. with performance sufficient to fulfill the real world applications). The adoption of Additive Manufacturing has also been amplified by its capability to realize uncommon design (such as hollow, trabecular, foam-like, honeycomb-like) features. Moreover, the integration between software solutions for design optimization, additive manufacturing and materials, leads to novel solutions for the enhancement of products shapes/performances (i.e.: weight-to- strength ratio, heat transfer characteristics, other needs related to the specific application), further enlarging the range of application for these technologies.

The document ISO/ASTM52921–1 [1] precisely defines the scope of these technologies as follows: Additive manufacturing is a *"process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies*".

The following list resumes the basic types of additive technologies listed in the same standard:

- Extrusion - molten material (usually polymers such as PLA or ABS) is selectively distributed by a nozzle, to create layer geometry. Process often used in low cost 3D printers. Also known as FDM (Fused Deposition Modeling) or FFF (Fused Filament Deposition).
- Jetting - "drops" of material (polymers, wax or metal) are sprayed selectively to create layers, then hardened by cooling or UV rays.
- Binder jetting - a liquid adhesive agent is sprayed on layers of powder (mineral, ceramics, cast sand).
- Sheet lamination - The artifact is created by the superposition of shaped sheets (paper, metallic), joined in various ways (glue, ultrasonic).
- Photo-polymerization - Selective solidification of a liquid polymer by electromagnetic radiations (usually supplied by la-

sers); it comprises the stereo-lithographic process.

- Powder bed fusion/sintering – a concentrated energy flow (laser or electron beam), locally melts or sinters a powder (metallic or polymeric) layer.
- Direct energy deposition - an energy flow, supplied by a laser, melts the material (metallic powder carried under laser focus by a nozzle) when it is layered to form the part.

2 CONSIDERATIONS ABOUT SAFETY IN ADDITIVE MANUFACTURING

The progressive and sometimes massive adoption of additive technologies in various manufacturing environments arises a number of new questions related to operators and workplace safety, mainly related to:

- Machine processes, often very different from the traditional machine ones
- Material used in process
- Operator habits and behavior
- Risk evaluation.

These questions are amplified when additive processes are performed in non-industrial environments (i.e. home/fab-labs for 3D printing or research laboratories for the development of new processes) or in industrial context operating with traditional processes (such as metal cutting/forming). Here, the adoption of additive technologies appears critical for safety, especially taking into account:

- occasional operators in non-industrial environments, not specifically aware of the risks related to the use of these technologies and using devices which can be at a prototype stage, self-build or sold by "uncertain" producers (often on-line);
- experienced operators for traditional processes, facing new and "unusual" processes and dealing with new materials and machines, sometimes clashing with established practice and habits.

Starting from these considerations, AITA-ASSOCIAZIONE ITALIANA TECNOLOGIE ADDITIVE proposed INAIL (National Institute for Insurance against Accidents at Work) to develop a set of documents to help the identification and elimination of hazards and/or reduction of risks in the use of Additive technology.

The use of these technical reports (to be written in bilingual text, Italian and English) is mainly related to end-users (employers, workers, other persons constantly or occasionally relating with devices used for additive manufacturing), to identify risks/actions and reduce them, according to actual legislation (at Italian and European level). Considering the profile of AITA members and the sectors that, by now, constitute the "backbone" of Additive Manufacturing applications, in particular, aerospace, biomedical/prosthetics, racing, automotive, jewelry and fashion, it has been decided to focus the attention and the contents of the first technical report to Power bed fusion /sintering, and safety, in particular to the application related to the manufacturing of metallic parts.

3 PROCESSES MACHINES AND RELATED HAZARDS

As defined in [1], Powder bed fusion/sintering process uses a concentrated energy flow (laser or electron beam), to locally melt or synthetize a (metallic) powder layer.

The process is carried on by dedicated machine tools, whose general schemes can be found in the following picture (Fig. 1) for laser based sintering/melting machines or in Figure 2 for Electron Beam Machines (EBMs).

4 LEGAL FRAMEWORK FOR SAFETY OF MACHINERY

AM machines are *de facto* machine tools and they have to be compliant with the "Machinery Directive (MD)", nowadays the effective directive is 2006/42/CE Directive [2]. In Italy, the decree D.Lgs. 17/2010 [3] actuated "Machinery Directive".

It must be noted that the design and the manufacturing of AM are not the scope of the Technical Report described in this paper. This task should be object of another technical report, targeted to machines manufacturers and not to end-users.

The compliance with "Machinery Directive" requires that the manufacturer (or, in some situations, dealers or importers) of machines satisfies the related safety requirements and provides, before placing on the market and/or putting into service the machine:

- the technical construction file: it is a means for the manufacturer to demonstrate the conformity of his product;
- the CE declaration of conformity: it provides essential information describing and identifying the machinery, including generic denomination, function, model, type, serial number and commercial name. Moreover it allows to identity the manufacturer of the machine and of his authorized representative, where appropriate; the person authorized to compile the technical file; the conformity assessment procedure that has been followed and the identity of

the Notified Body involved, where appropriate;

- Instructions describing the procedures to be carried out by operators, maintenance specialists and any other person relating with the machine operative life cycle (from installation to dismantling and disposal);
- The CE marking: a label fixed on the machine that demonstrate the compliance with Machine Directive.

We also remind that the risk assessment related exclusively to the machine design and construction is performed by the manufacturer whose evidence consists in the documents previously detailed. These documents confirm the compliance with "Machinery Directive". The manufacturer of the machine has to individuate possible hazards and to define technical measures and procedures in order to minimize the related risks, basing on standards, good practice and legislation (as described in the machine technical file document). Drawing the instruction he will identify also residual risks after adoption of all protective measures. We remind that each AM machine must be accompanied by instruction, CE declaration of conformity and CE marking.

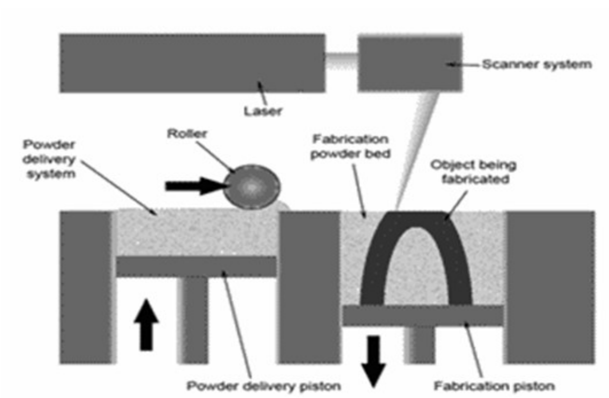

Figure 1 – schematic view of a laser based sintering/melting machines [5]

5 LEGAL FRAMEWORK FOR SAFETY AT WORK

The legislative context, on which the technical report is based, is D.Lgs. 81/08 e s.m.i. (i.e. the legislative decree 81/08 and its further modifications and integrations) [4]. It is an Italian Decree, which is anyway, largely based on the European legislation.

The D.Lgs. 81/08 defines a set of legislative rules, valid within Italy, in terms of safety and health at workplaces. It groups, integrates and harmonizes all the Italian legislative instruments related with the above topic, actuating the 1st article of law n. 123 released August 3, 2007.

In particular, D.Lgs. 81/08 defines the responsibilities of the subjects involved in safety and health at workplaces, ranging from employer of the company (the so called "datore di lavoro"), to the intermediate responsibles (the so called "preposti"), to the worker (operators and other persons relating with the AM process). All of this creates a responsibility and control chain that ensures the enforcement of the related regulations, as well as the surveillance on the effectiveness and application of measures and company safety procedures.

As legislative instrument, it also individuates the public authorities in charge of the surveillance in workplaces and the respective fine.

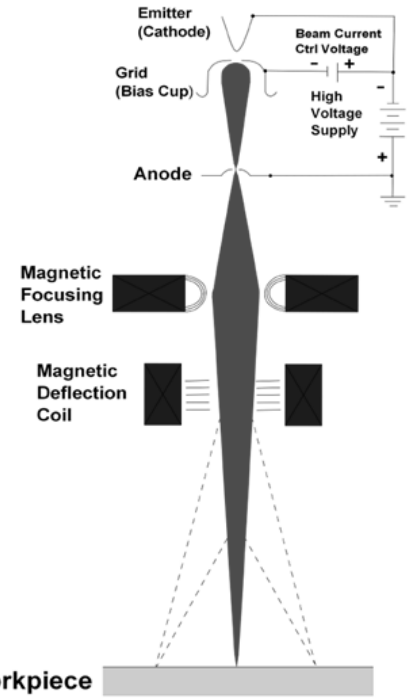

Figure 2 – schematic view of an EBM machine [6]

Moreover, D.Lgs. 81/08 requires an implementation process based on risks analysis. It is exclusively in charge to the employer and he/she develops the risk analysis for any activity. The process generates a document that is the base for any action concerning health and safety at workplaces and the related implementation activities. D.Lgs. 81/08 also requires a continuous improvement action, substantially based on a PDCA (Plan-Do-Check-Act) approach.

Symmetrically to the machine manufacturer, the employer, according to D.Lgs. 81/08, shall carry out the risk analysis, taking into account possible cause of hazard for any specific application, in order to:

a. identify mandatory and further protective measures for the reduction of risks related to power bed fusion/sintering machines use in the workplace;
b. inform and train the workers involved in the operations and define proper training steps, allowing them to prevent any dangerous or harmful situation.

Among the protection measures that the employer has to implement, there is the use of PPE - personal protective equipment (protective clothes, breathing devices, gloves, shoes).

Developing the risk analysis the employer takes into account all the persons involved, both internal and external, i.e. visitors, customers, supporting personnel that can be in the place where the machine is installed and used.

6 METHODOLOGY AND RESULTS

The activities of the established working group started from the definition of some possible hazardous scenarios, taking into account the typical workplaces. As stated by risk analysis principles, the probability that these hazards can compromise operators' health/safety has to be evaluated.

The main hazards that have raised from this analysis are:

- mechanical hazard, related to:
  a. moving parts of the machines (i.e. powder leveling device, transmissions);
  b. sharp edged parts, corners, rough surfaces (i.e. elements of the machine made in sheet metal);
  c. fall or projection of parts (i.e. construction plate, gas bottles, powder containers);

- electrical hazard, related to:
  a. electromagnetic phenomena (i.e. emitted by the machine electrical circuits or devices);
  b. electrostatic phenomena (i.e. produced by powder flowing, charge accumulation within plastic bags or container, sweeping floor using wrong devices);
  c. electrified parts (i.e. internal circuits accessed during maintenance);
  d. parts becoming conductive in case of machine failure (i.e. accidental contact with broken cables);

- hazard due to contact with hot surfaces:
  a. very hot surfaces (i.e. part of the machine heat during the manufacturing process);
  b. very hot materials (i.e. surrounding the finished part before its extraction from the machine);
  c. fire and explosions (i.e. caused by reactive powders, such as Aluminum or Titanium, accidentally reacting with air oxygen or water);

- hazards caused by radiations, related to:
  a. optical radiations (i.e. laser beams);
  b. ionizing radiations (i.e. X-rays emitted by EDM process);

- hazards due to emission of materials and substances such as:
  a. micro- or nano- powders (i.e. generated during powder/parts handling or by the process);
  b. flammable or reactive materials (i.e. used during the process or during the maintenance of the machine);
  c. inert gases (used to isolate the process from the air oxygen).

Considering all of the above-mentioned items, first the manufacturer must take into account all the solutions leading to the elimination or reduction of risks, based on the actual state of the art and the related available technical standards. Then the employer will build his/her risk assessment related to the specific workplace where the machine shall be installed.

The activities and relative technical report follows exactly the PDCA approach, pursuing the main target to support end-users to comply the safety regulations and to manage a new and unconventional landscape of safety issues.

7 CONCLUSIONS AND FUTURE DEVELOPMENTS

The first technical report contains and deals with the main regulatory references currently existing for the type of machines considered.

Additive manufacturing launches new challenges for the design of products and technological aspects in general, but the related safety and legal issues are equally important and complex. For these reasons the authors, supported by a group of experts, have developed a technical report related to the process having, at the moment, the higher interest at industrial level, i.e. the Power bed fusion/sintering of metallic powders.

The technical report is going to be shared with Italian Ministry of Labor and Social Policy and other local governmental boards such as Machines and Plant Interregional Group. This sharing could represent a first step for its formal validation.

After the official publication of this technical report, INAIL and AITA will start working with the support of companies, to create further technical reports, taking into account other materials (polymers are probably the next) and processes, in order to further increase the safe applications of these new technologies, according to law and directives. Furthermore, the technical report will be also used as fundamental reference in activities related to the training of operators, putting safety as the main aspect of the competences to be transferred to students.

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