INNOVATIVE CONTINUOUS PROCESS FOR AM METAL POWDER PRODUCTION

Additive Manufacturing and Metal Making

Michela Boccadoro
TENOVA

Organizzato da

Agenda

- Introduction
- Market outlook
- Additive Manufacturing vs. Subtractive Manufacturing
- Technological constrains to broader adoption
- Traditional AM powder production process
- Tenova’s vision for Additive Manufacturing
- Tenova process: Main challenges
- Tenova process: Simulation and test outputs

FEDERAZIONE NAZIONALE IMPRESE ELETTROTECNICHE ED ELETTRONICHE

CONFINDUSTRIA

Introduction

- **Additive manufacturing** is an alternative technology to produce metal parts, using a range of materials, from plastics to metals.

- This presentation outlines Tenova's technological vision towards the development of a **large scale AM powder production** able to leverage economies of scale and lower production costs.

INDUSTRIES	CURRENT APPLICATIONS	POTENTIAL FUTURE APPLICATIONS
COMMERCIAL AEROSPACE AND DEFENSE[17]	• Concept modeling and prototyping • Structural and non-structural production parts • Low-volume replacement parts	• Embedding additively manufactured electronics directly on parts • Complex engine parts • Aircraft wing components • Other structural aircraft components
SPACE	• Specialized parts for space exploration • Structures using light-weight, high-strength materials	• On-demand parts/spares in space • Large structures directly created in space, thus circumventing launch vehicle size limitations
AUTOMOTIVE[18]	• Rapid prototyping and manufacturing of end-use auto parts • Parts and assemblies for antique cars and racecars • Quick production of parts or entire	• Sophisticated auto components • Auto components designed through crowdsourcing
HEALTH CARE[19]	• Prostheses and implants • Medical instruments and models • Hearing aids and dental implants	• Developing organs for transplants • Large-scale pharmaceutical production • Developing human tissues for regenerative therapies
CONSUMER PRODUCTS/RETAIL	• Rapid prototyping • Creating and testing design iterations • Customized jewelry and watches • Limited product customization	• Co-designing and creating with customers • Customized living spaces • Growing mass customization of consumer products

Sources: Deloitte analysis; CSC, *3D printing and the future of manufacturing*, 2012.

Graphic: Deloitte University Press | DUPress.com

tenova

Market Outlook

Analyst consensus

- 3D printers build rates to be increased
- Increasing powders volume and reducing production costs
- Entrance of larger players with higher investment budgets may bring down cost
- Automotive industry is starting to plan quite relevant budget on AM

News according to Market Reports

- Global metal powders for AM to expand at a robust **20-25% CAGR** between 2018 and 2024, if adoption across industries continues at today's rate.

Source: Markets&Markets

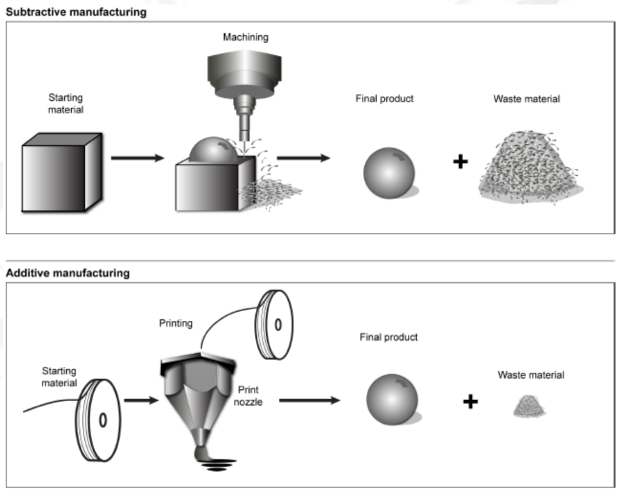
Additive Manufacturing vs. Subtractive Manufacturing (1)

subtractive

vs.

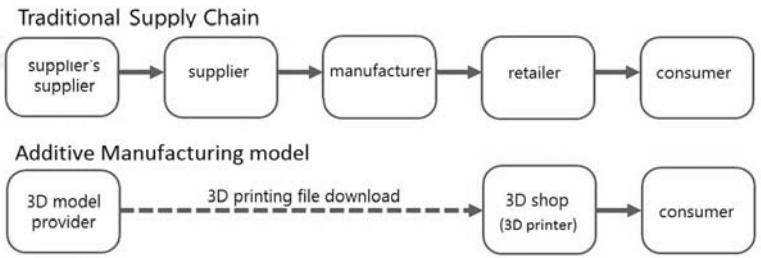
additive

Waste Comparison



Sources: GAO (analysis); Art Explosion (images). | GAO-15-505SP

Value Chain Comparison



FEDERAZIONE NAZIONALE IMPRESE ELETTROTECNICHE ED ELETTRONICHE

CONFINDUSTRIA

Additive Manufacturing vs. Subtractive Manufacturing (2)

subtractive

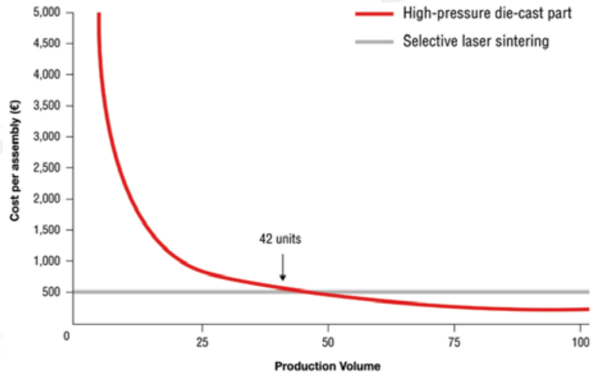
VS.

additive

Additive allows a **greater design freedom**

AM

- **Cost effectiveness at small scale**
- **Time effectiveness** at small scale



The breakeven point for high-pressure die-casting and selective laser sintering, a powder bed fusion AM technique.

Source: Costs and Cost Effectiveness of Additive Manufacturing, National Institute of Standards and Technology (2014) <http://dx.doi.org/10.6028/NIST.SP.1176/>

tenova

Additive Manufacturing vs. Subtractive Manufacturing (3)

subtractive

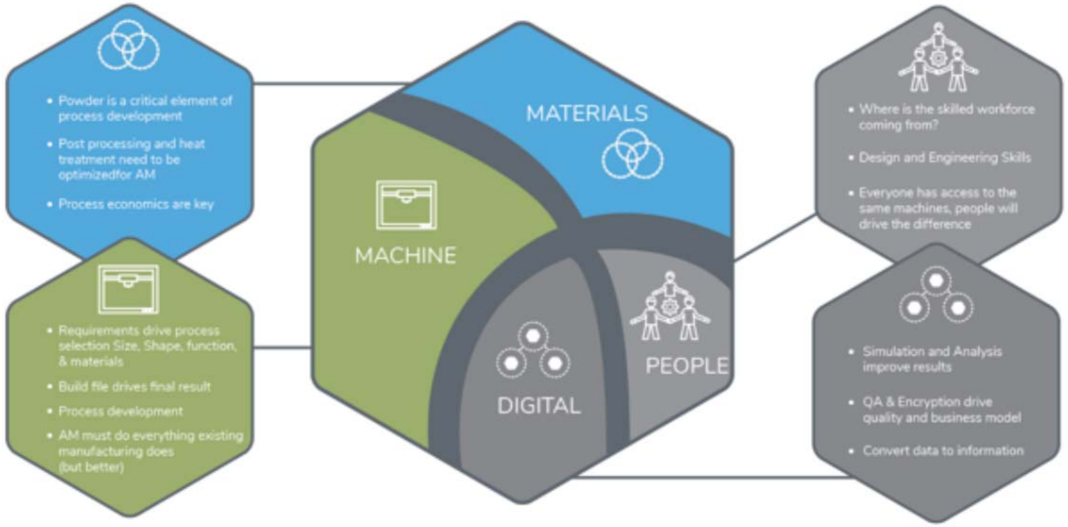
VS.

additive

	Production Manufacturing Costs	Inventory & Warehouse Costs	Import Fees, Taxes	Shipping, Transportation Costs
Standard Manufacturing	+	−	−	−
AM Manufacturing	−	+	+	+

Technological constrains to broader adoption

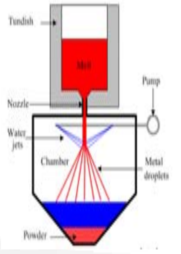
- **Size limitations**
- **Limited multi-material capabilities**
- **Quality consistency**
- **Narrow range of materials and high material cost**
- **Compliance and regulations**
- **Further training requirements**
- **Industrial standards to be substantially changed**

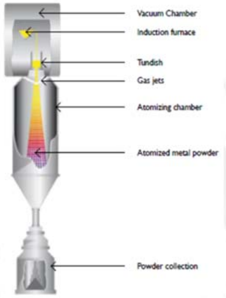


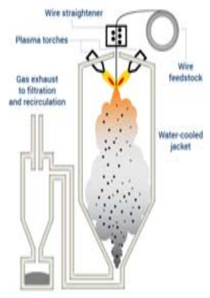
ASTM INTERNATIONAL ISO

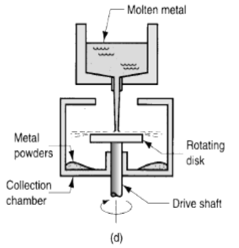
tenova

Traditional AM Powder Production Process (1))









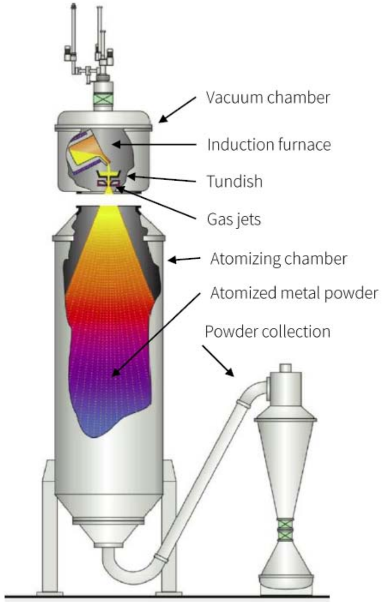
Type	Water Atomization (WA)	Vacuum Induction Gas Atomization (VIGA)	Plasma atomization (PA)	Centrifugal atomization (CA)
Raw materials	Scrap, coke, DRI, fluxes, alloys melted in electric arc or basic oxygen furnaces	Ingots, bars, pre-casted metals, ferroalloys, selected scrap, melted in Induction Furnace	Previously used metal powders or wire of suitable diameter	Metal, non-metals or alloys like Cu alloys, Zn, steels in graphite or steel crucibles.
Products	Iron, steel powder for pressing, sintering, etc.	Steel powders, Ni-Co alloys, some Ti alloys involved in powder metallurgy (AM, Coating, MIM, etc.) and related applications	High quality powders, like Ti and superalloys	Narrow and spherical powders
Notes	Combination of atomization process with melting plant in steel mill is a technological solution well consolidated, but it is not compatible with AM market	Able to process many alloys including those required for AM and to atomize compositional variation of alloys in order to adapt them for AM process.	Mostly used in the AM sector due to its ability to achieve highly spherical powder	High-speed rotation of the disc causes the metal droplets to be formed on the walls of the chamber. Used in AM due to spherical particles obtained and no internal porosity but requires large diameters of chamber.

Traditional AM Powder Production Process (2)

VACUUM INDUCTION GAS ATOMIZATION (VIGA)

Basic Production Steps

- Vacuum Induction Melting (VIM) furnace where the alloys are melted, refined and degassed
- The refined melt is poured through a preheated tundish system into a gas nozzle where the melt stream is disintegrated by the kinetic energy of a high pressure inert gas stream
- The metal powder produced solidifies in flight in the atomization tower located directly underneath the atomization nozzle



The VIGA Atomization cycle is composed by some separate steps (melting, alloying, atomization, tundish substitution) and it means a processing time of **4 hours** and 500 kg of solid charge.

FEDERAZIONE NAZIONALE IMPRESE ELETTROTECNICHE ED ELETTRONICHE

CONFINDUSTRIA

Tenova **Vision** for Additive Manufacturing (1)

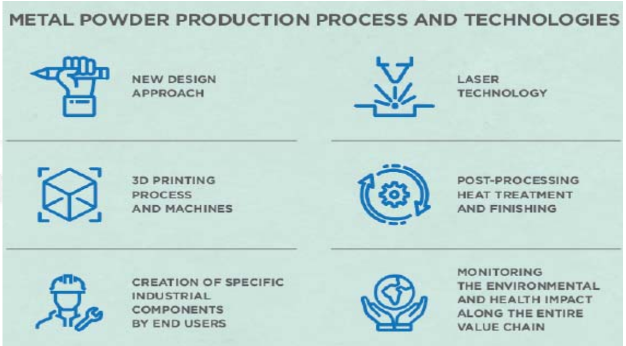
- Tenova is carrying out several initiatives: the EU-funded research project **MADE4LO**, a new internal IP, market investigations and selected partnership agreements
- An **Innovative Continuous Metal Powder Production Process** has thus been developed specifically for the Additive Manufacturing market, with particular focus on the 3D printing sector
- The new IP has been protected with the appropriate patent developments
- A long term cooperation agreement has been signed with a first class technology partner in gas atomization

➢ **Tenova is currently the most innovative technology provider for the AM powder sector**

MADE4LO
METAL ADDITIVE FOR LOMBARDY

...an Italian region **on the wave of digital transformation** with long tradition in manufacturing, **9 companies and 2 universities led by Tenova** have launched an exciting initiative called **Metal Additive for Lombardy**. The total **investment of 6.6 million euros** is partly funded **by the European Regional Development Fund** in the framework of **Lombardy Region's Research and Development Agreements.**

The **partners** will create an **interconnected widespread factory** to **integrate** the entire value chain of **Additive Manufacturing** in the **local industrial ecosystem.**



tenova

Tenova **Vision** for Additive Manufacturing (2)

The pillars of Tenova process cost advantages:

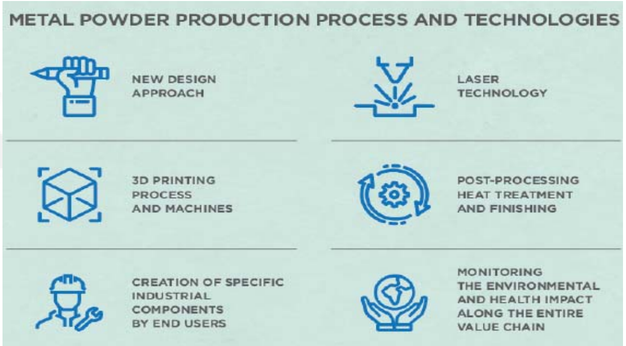
- **Low raw material cost**
- **High productivity ratios**
- **Continuous and stable process**
- **High yield in the 3D printing size ranges**
- **Ability to produce tailored non-reactive alloys**

tenova

MADE4LO
METAL ADDITIVE FOR LOMBARDY

...an Italian region **on the wave of digital transformation** with long tradition in manufacturing, **9 companies and 2 universities led by Tenova** have launched an exciting initiative called **Metal Additive for Lombardy**. The total **investment of 6.6 million euros** is partly funded **by the European Regional Development Fund** in the framework of **Lombardy Region's Research and Development Agreements.**

The **partners** will create an **interconnected widespread factory** to **integrate** the entire value chain of **Additive Manufacturing** in the **local industrial ecosystem.**



Tenova **Vision** for Additive Manufacturing (3)

Tenova, owner of Intellectual Property (IP) for producing high quality molten metal, is developing the design for a new process for metal powder production, also through gas atomization.

With the aim of getting a continuous process, the following steps are comprised:

- **Melting station**
- **Refining station**
- **Heating and Holding**
- **Atomizing**
- **Extracting**

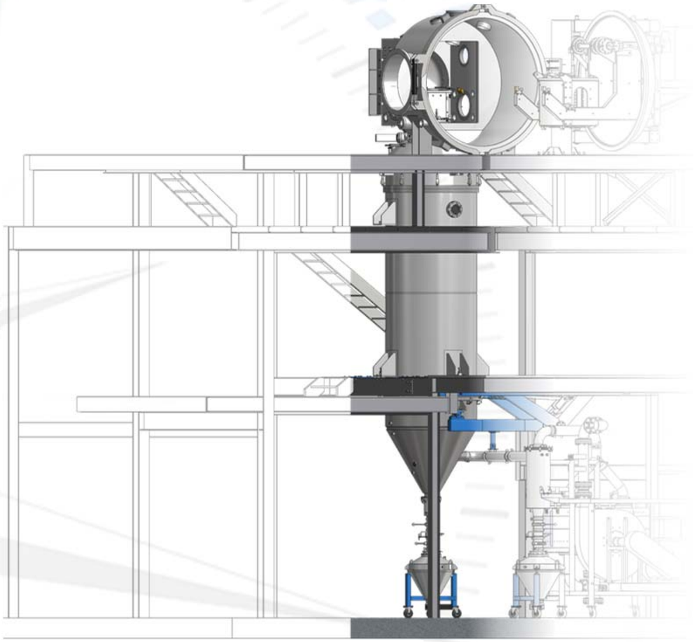
tenova

FEDERAZIONE NAZIONALE IMPRESE ELETTROTECNICHE ED ELETTRONICHE

CONFINDUSTRIA

Tenova Process: Main challenges – PROCESS

- **The vast majority of the world's VIGA atomizers are batch operation: four hours is spent atomizing.**
- **With Tenova Process, atomization is continuous.**
- **With Tenova Process, productivity will increase by a factor 4 compared to the conventional VIGAs**
- **With quick change out facilities being installed, productivity will rise up to over 90%, making powder production comparable to that achieved in continuous casting of steel.**
-
- **With Tenova Process, OPEX will considerably descrease. E.g. Up to a factor 3 to 4 for metal grades such as AISI 316L**



tenova

Tenova Process: Main challenges – DIGITAL SOLUTIONS

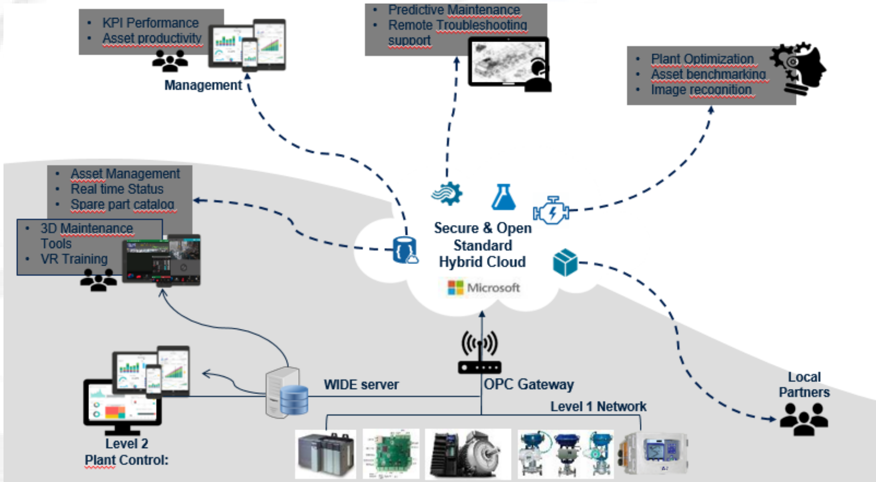
- **System automation enhanced to industry 4.0 levels**

- **Tenova Digital know-how in terms of AI/machine learning coding in order to address different targets by means of:**

  - Image learning coding
  - Sound learning coding

- **Robotic applications**

- **Reporting and maintenance manual on virtual devices such as tablets and smartphone, connected to IoT platform**

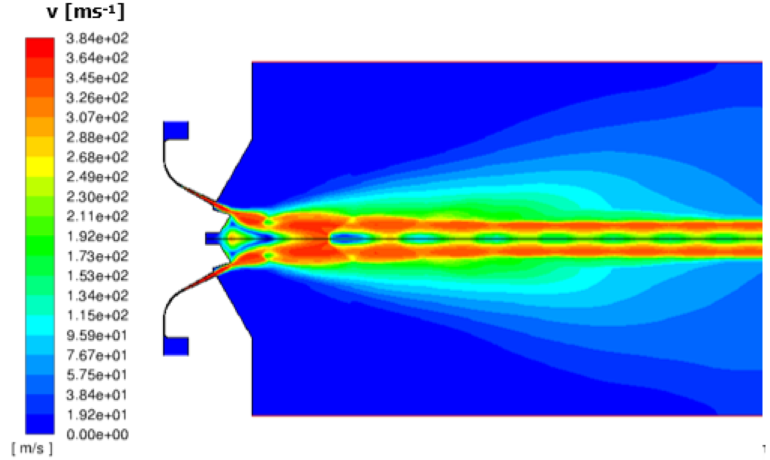


tenova

Tenova **Process: Simulation** and Test Outputs (1)

- In 2017 Tenova implemented a simulation activity on the innovative process by means of:
  - Atomization of AISI 316L powder batches in an R&D facility
  - AISI 316L 3D printed test samples

- In 2018, **BeeMetal Corp.**, a new-co that embraced the challenge of AM, started the development of the Tenova process making semi-industrial and producing Stainless Steel 316L powder.



➢ **Outputs…**

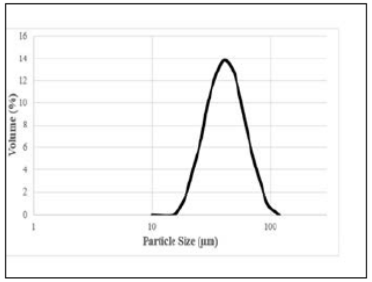
Tenova Process: Simulation and Test Outputs (2)

Produced AISI 316L Powder demonstrates:

- Spherical shape to ensure a good flow ability
- Homogenous particle sizes distribution
- Controlled chemical composition
- Low level of small inclusions
- Low concentration of un-desired elements like Nitrogen, Oxygen and Hydrogen
- Considerably high level Yield

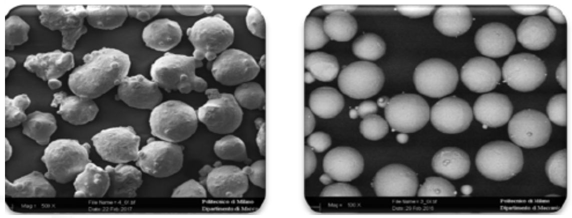
Powder Atomization Yield:
One of the critical factors to meet this goal is to maximize the yield of powder in a size range between 15μm and 48μm. Industrial tests conducted resulted in a **49.60% yield** in that size range, with a d_{50} of 27μm. **This is an almost 20% increase of yield compared to the values of the traditional VIGA systems for the same size range.**

Particle size distribution (PSD)

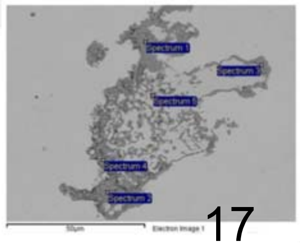


Quantitative:
- Laser diffraction
- Sieving
- Microscopy

Particle shape



Qualitative:
- SEM



Inclusions Analysis

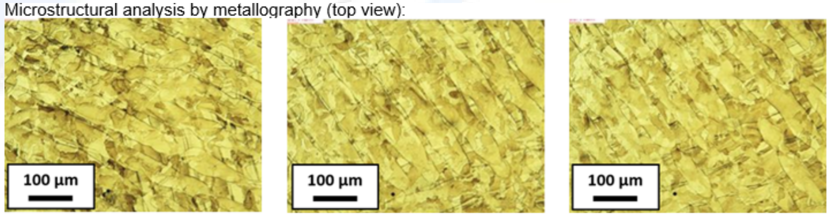
Tenova **Process: Simulation** and Test Outputs (3)

BeeMetal Stainless Steel 316L tests demonstrates:

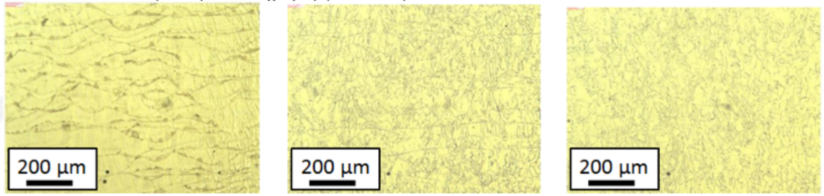
- **Chemical composition** corresponds with the chemical analysis of the virgin powder
- Sintered **density** tests per ASTM B962. No substantial or appreciable differences among the different samples has been observed. Overall density of 7.972 grams per cubic centimeter, or 99.66%, was achieved.
- High density confirmed by the metallography tests, which show a **very uniform metal structure**.
- The **UTS and elongation** results are exceptionally

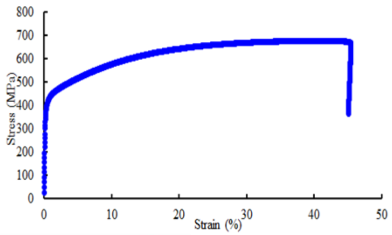
  high compared to the same available in the market.

Microstructural analysis by metallography (top view):



Microstructural analysis by metallography (side view):





Control mode: displacement control

Displacement rate (mm/min): 1.6

Young's modulus (GPa): 202

0.2% offset yield stress (MPa): 395

UTS - Ultimate tensile strength (Mpa): 678

Fracture strain: 45%

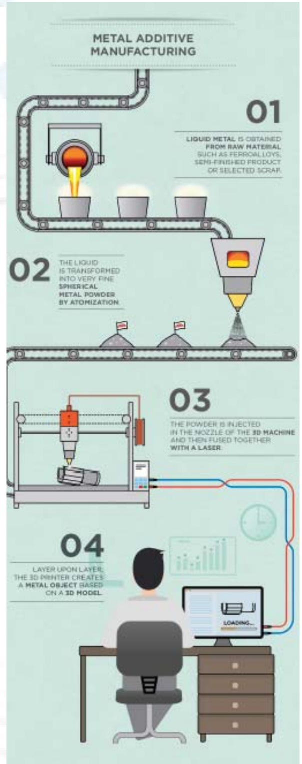
FEDERAZIONE NAZIONALE IMPRESE ELETTROTECNICHE ED ELETTRONICHE

CONFINDUSTRIA

Conclusion (1)

- Tenova's innovative route for low-cost powder production is a disruptive method for large-volumes of high-quality metal powder production to be used in 3D printing

- The outputs of the Tenova and BeeMetal testing activities validates the new production method that is capable of delivering higher quality powder metal products



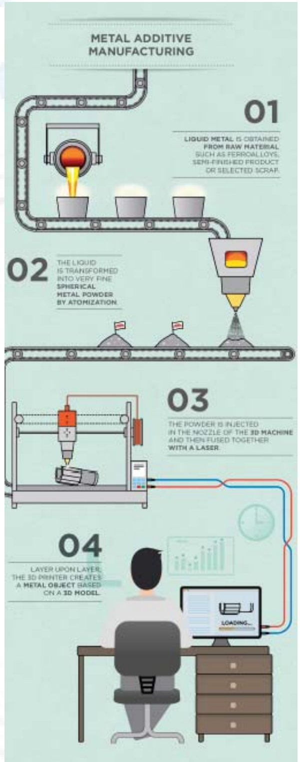
Conclusion (2)

Reference market

- Green field projects (Beemetal business case)
- Metal makers with EAF for liquid steel diversification to a high-revenue market
- New business opportunities for scrap supplier
- Foundry & forgery to prevent their revenues from downsizing due to AM increase

Tenova possible value chain positioning

- As powder plant supplier
- As technology provider in a partnership with all actors (liquid metal provider and atomizer, powder trader, 3D printing company service)



Thank you for the attention

THE SMART WAY TO METALS

Discover a green and more efficient way of producing metals

Tenova SpA

michela.boccadoro@tenova.com