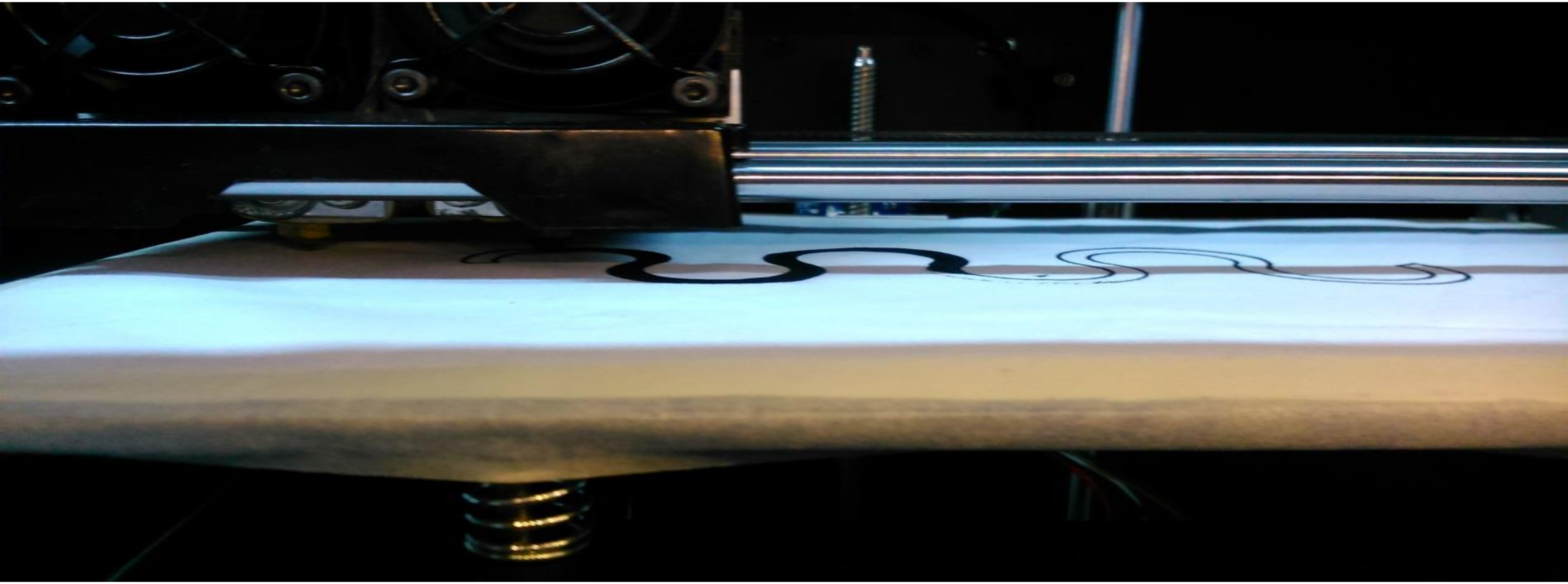
3D printing on textiles:
A novel process for functional and smart textiles



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3D printing on textiles:
A novel process for functional and smart textiles

Contents

Keywords

3D printing, additive manufacturing, Fused deposition modeling, adhesion, pressure sensor, electroluminescence, electromyography

Functional and Smart Textiles

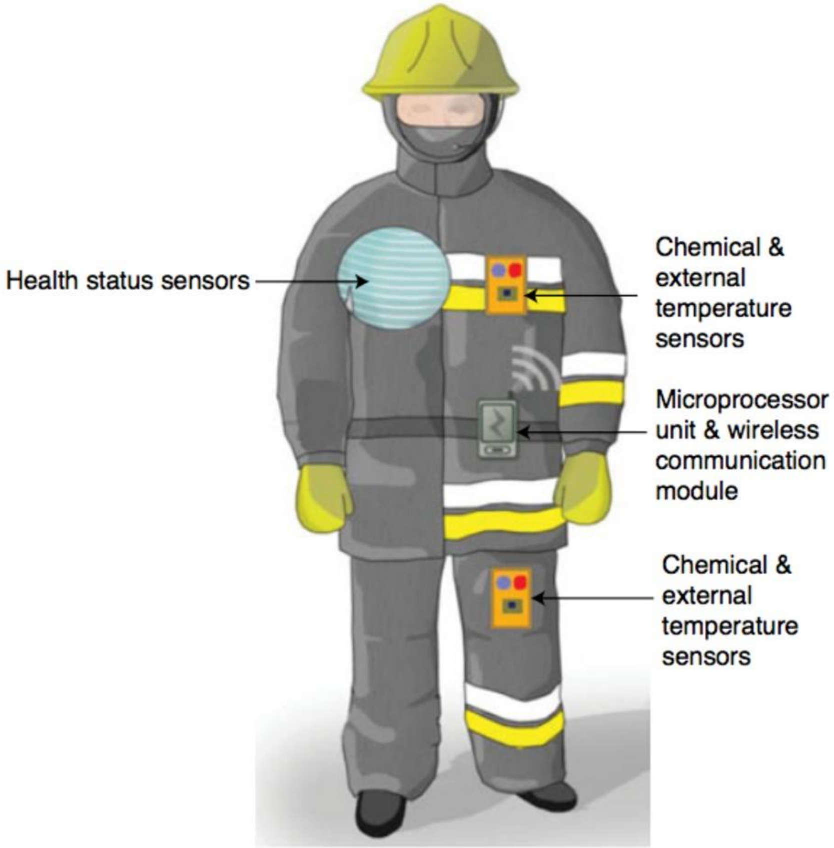
Functional and smart textiles are used for different purposes such as healthcare, interior textiles, automobile, protective clothing, communication and entertainment, and are represented by different products like medical shirt, carpet, car sit, firefighters suit and optical fiber display. These are the common applications, but there also some applications like ergonomic clothing.

Heart-rate monitoring shirt

www.dr-hempel-network.com

Wearable technology for firefighters

www.firehouse.com



Wearable RF electronic for high speed communication

Wang, Z. *et al.* In Electronic Textiles: Smart Fabrics and Wearable Technology; 2015.

Problems and Challenges in development of Functional and Smart Textiles

There are some problem and challenges in development of functional and smart textiles which are mostly influenced by cost and economy. Big companies push a product to the market when the technology is able to support the large scale production. As the existing technologies can not respond to customized production, the products hardly come to the market.

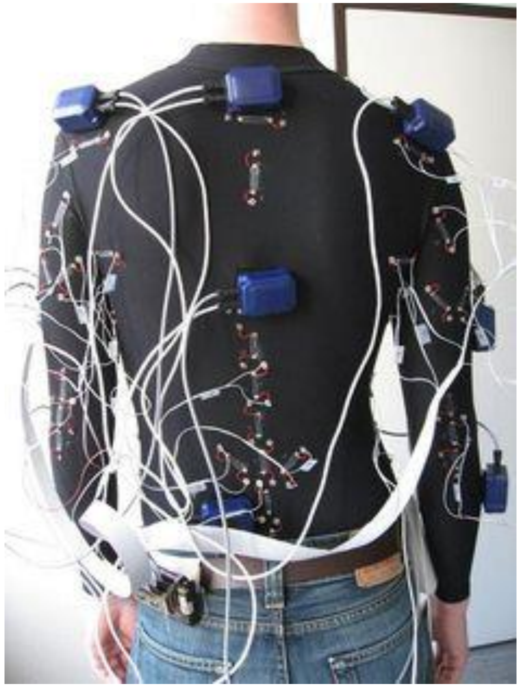
Problems

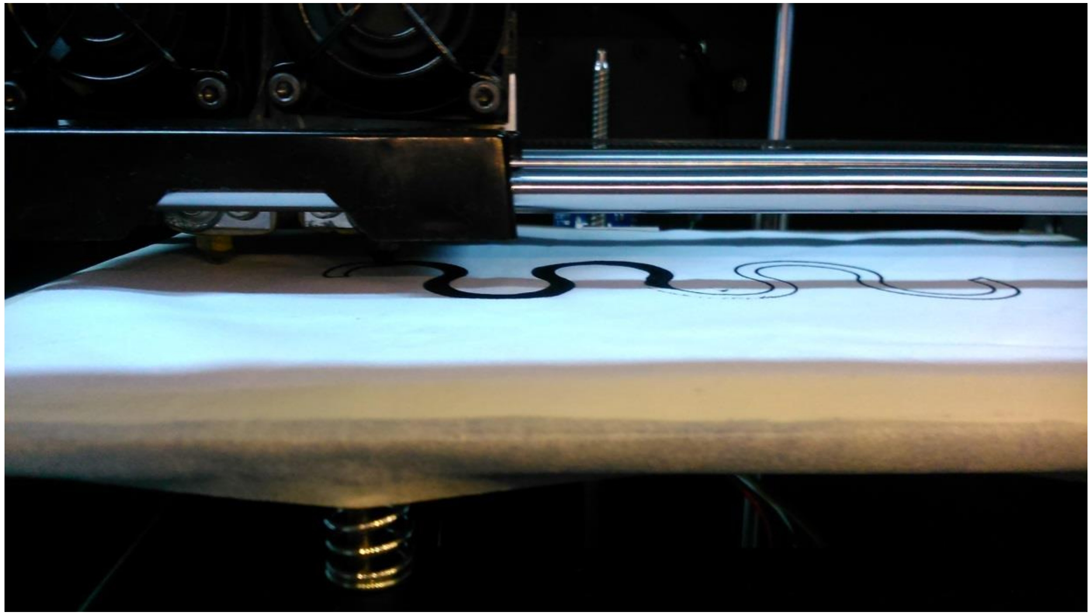
- **Economy**
- **Production scale**
  - **Customized production**
  - **Processing and fabrication and their compatibility with existing equipment**

Challenges

- **Standards**
- **Awareness and education**
- **Integration of the functions**

✓ **Introduce more flexible technologies to open up new opportunities and fulfill the requirements of a functional and smart textile such as cost and flexibility**

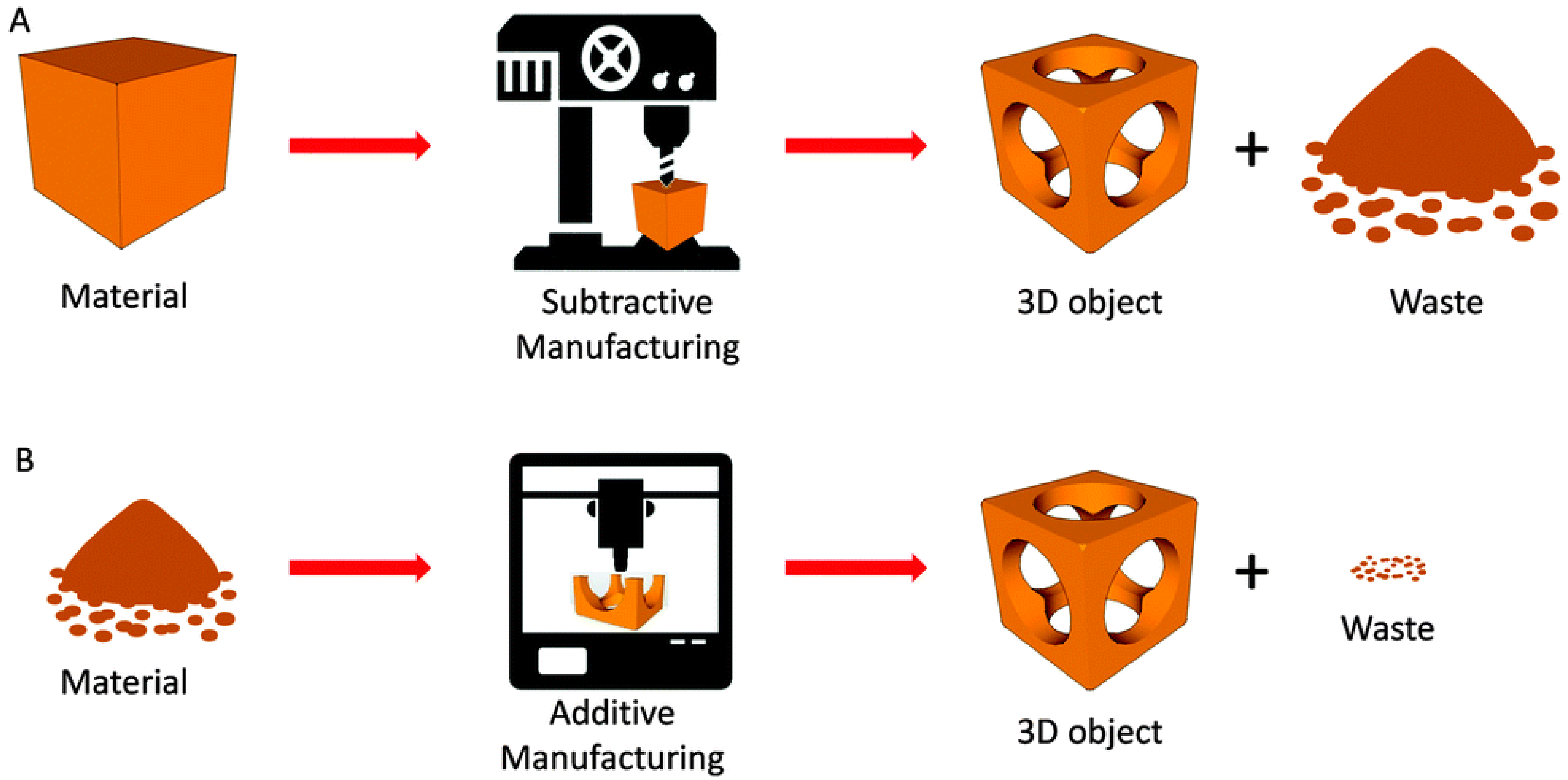




Replacing sensors and interconnections in smart textiles by depositing 3D printed nanocomposites onto textiles

3D Printing
(A) Subtractive manufacturing (B) Additive manufacturing

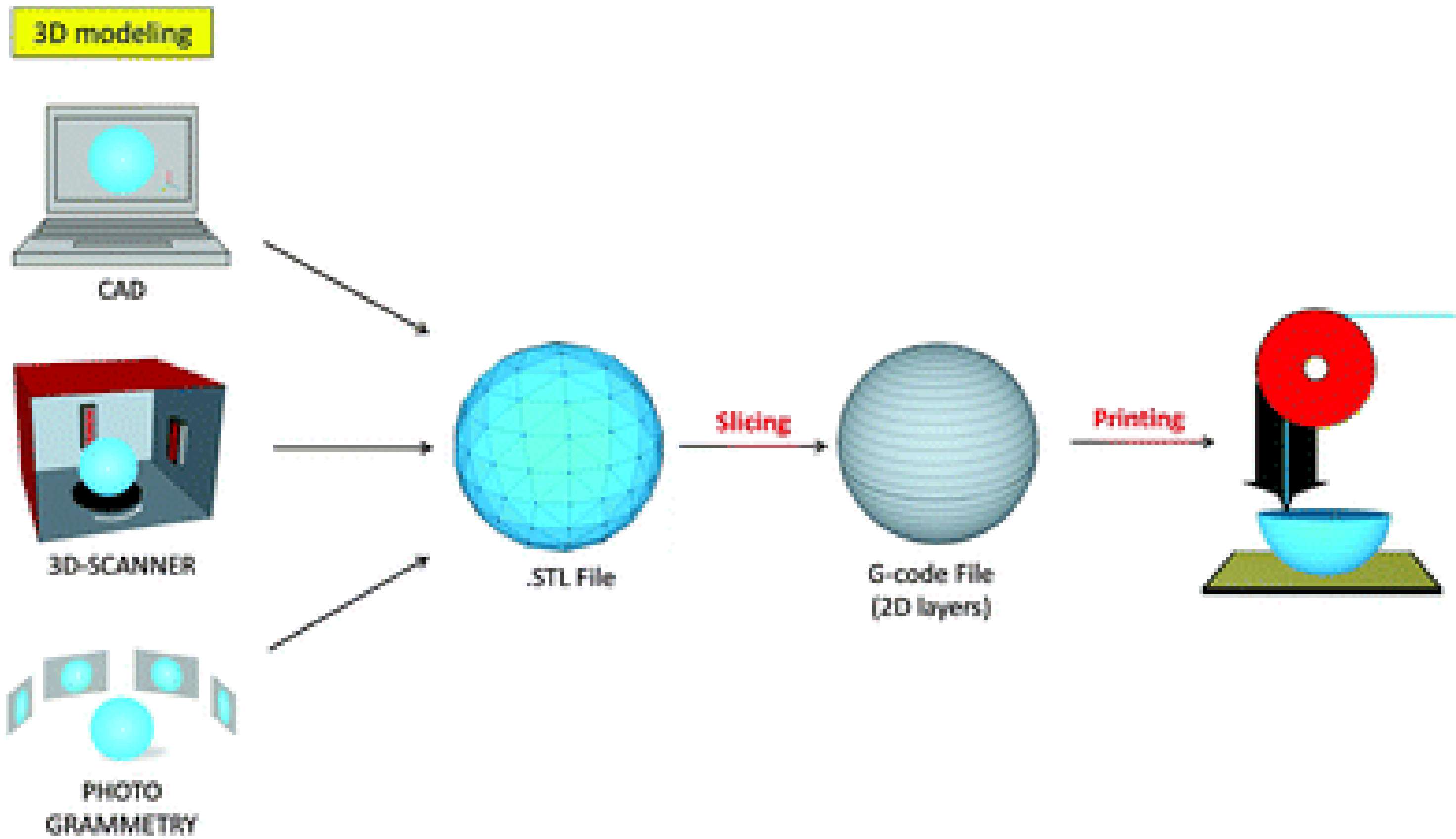
The world of 3D printing holds a wide range of technologies. At the highest level, there are three major categories for production of a 3D part including forming, subtractive or additive manufacturing. In the forming, the material will be reshaped. In subtractive methods as you can see in the figure, unwanted material will be removed from the 3D object with different methods like cutting or etching. In additive manufacturing, the 3D object will be formed by the layer-by-layer building process. The method begins with a 3D model designed with CAD software. This model then digitized and sliced into model layers with special software. Accordingly, 2D layers will be 3D printed into a 3D build.



A. Ambrosi and M. Pumera, Chem. Soc. Rev., 2016, 45, 2740-2755.

Additive manufacturing process

- Image via e.g. 3D scanner
- Create digital file, e.g. Autocad, Scan
- STL file (Standard Tessellation Language, describe only the surface geometry of a three-dimensional object without any representation of color, texture or other common CAD model attributes.
- Layer by layer building of the object (G-code)



A. Ambrosi and M. Pumera, Chem. Soc. Rev., 2016, 45, 2740-2755.

Additive manufacturing

Overview of monomer/polymer material used with specific layered building methods in additive manufacturing

The main difference between several additive manufacturing processes are in the used material and the way of layer deposition.

Material

- Liquid resin
- Polymer powder
- Polymer filament
- Polymer films

Pattern/fuse

- Optical
- Chemical/Mechanical
- Thermal

Print technology

- SLA/DLP
- MultiJet/PolyJet
- SLS
- Binder Jetting
- SHS
- FFF/FDM
- LOM

SLA: Stereolithography apparatus,
DLP: Digital light projection,
SLS: Selective laser sintering,
SHS: Selective heat sintering,
FFF: Fused filament fabrication,
FDM: Fused deposition modelling,
LOM: Laminated object manufacturing

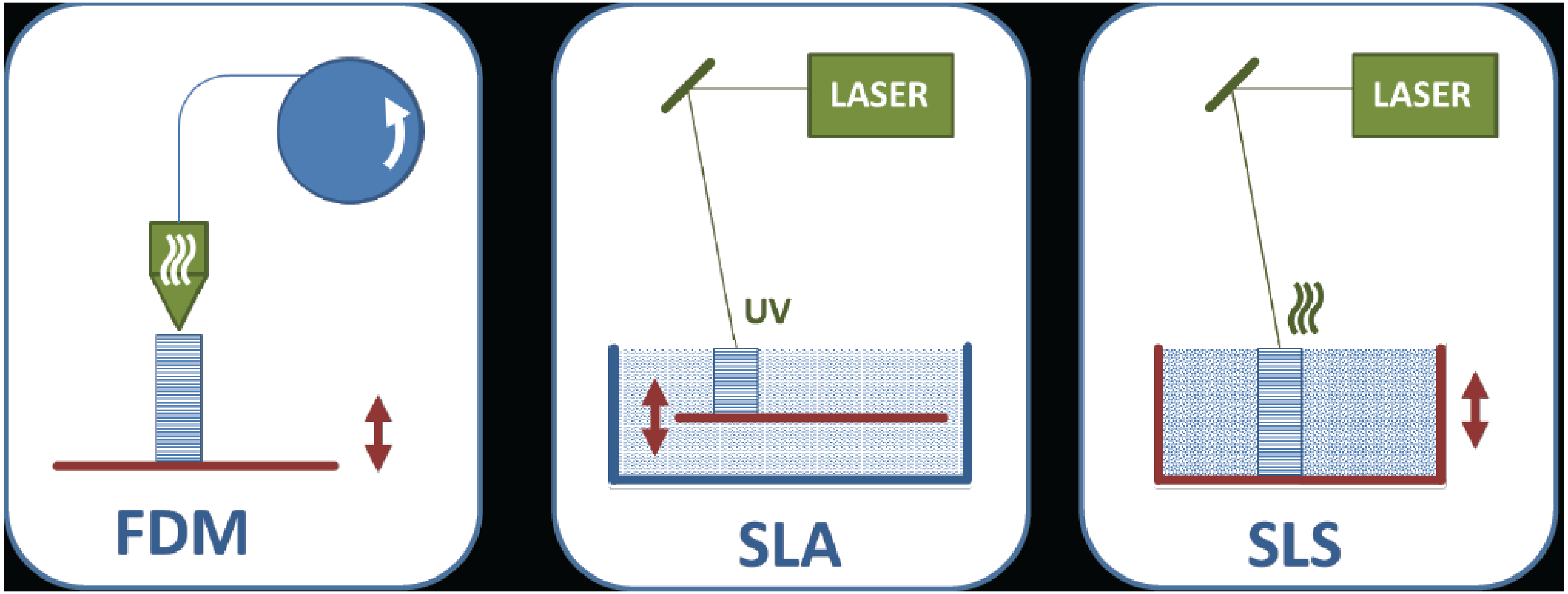
J. W. Stansbury and M. J. Idacavage, Dental Materials, 2016, vol. 32, no. 1, pp. 54–64.

Additive manufacturing: Techniques example

Fused Deposition Modeling based on
Heating and extrusion

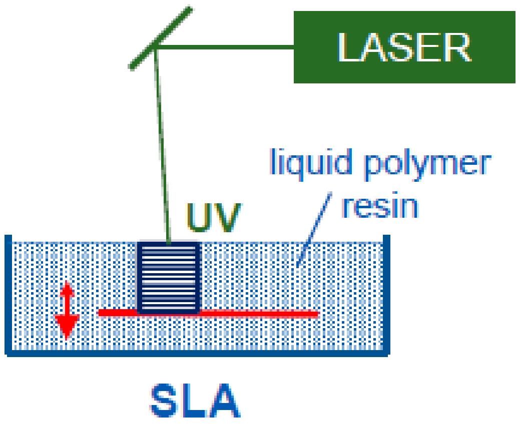
Stereolithography
based on
photo-solidification
of a UV curing polymer

Selective laser sintering
based on sintering powdered
material by laser

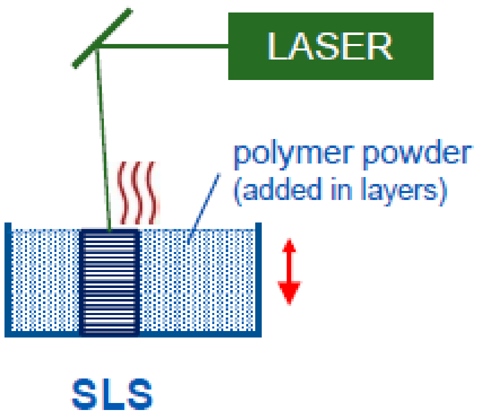


Additive manufacturing: Techniques example

Advantages and disadvantages



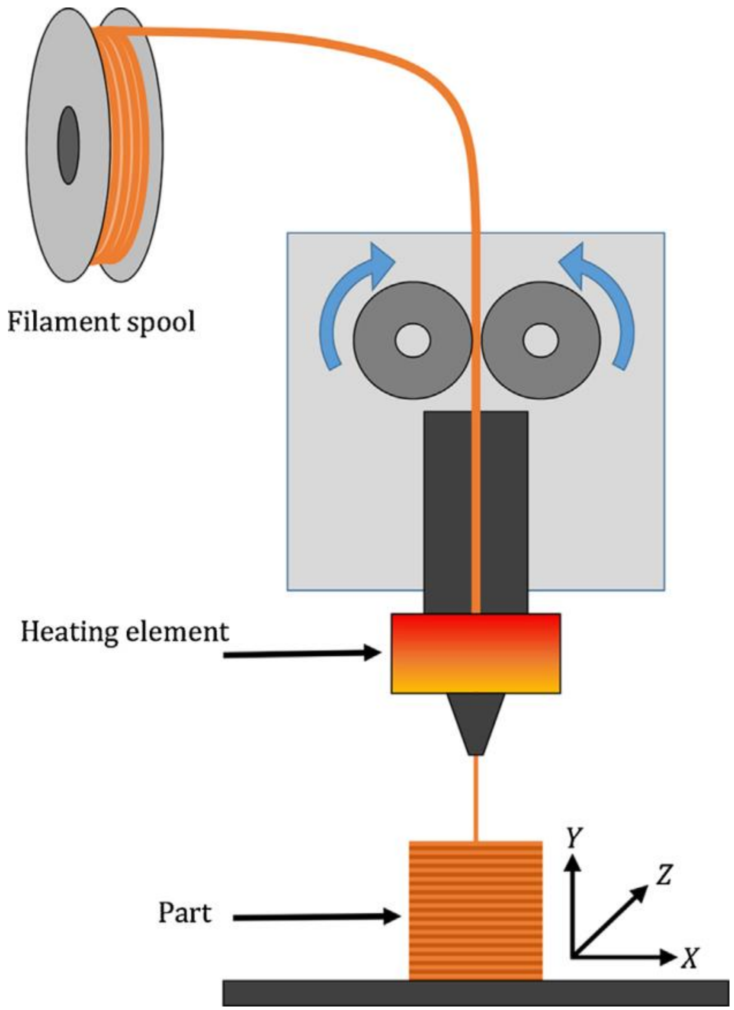
- ☺ First available additive manufacturing process
- ☺ Excellent accuracy
- ☹ Use of liquid photosensitive polymers (toxicity)
- ☹ Limited durability/stability



- ☺ High bandwidth of materials
- ☺ High mechanical strength
- ☹ Rough surface
- ☹ High cleaning efforts
- ☹ High machine costs

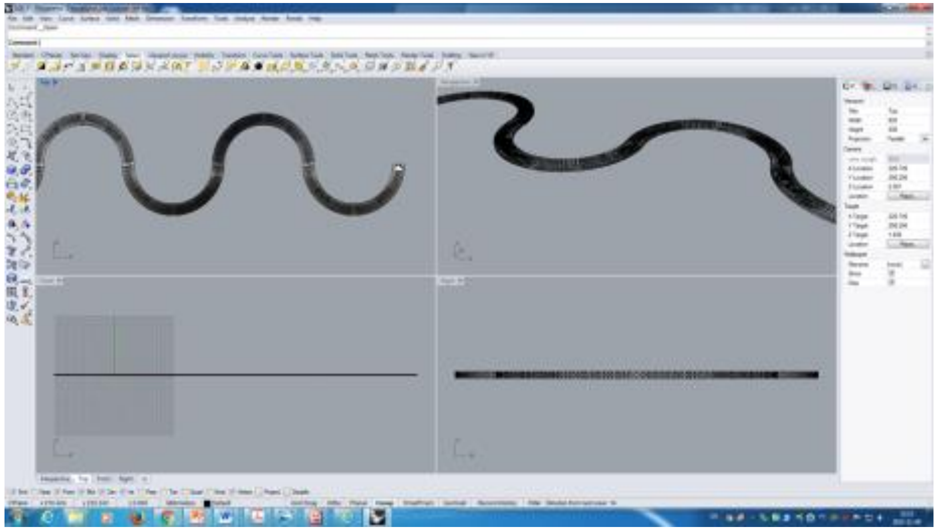
Fused Deposition Modeling (FDM)

- Based on heating and extrusion
- Use thermoplastics materials in filament form
  - hard: ABS, PLA, PA
  - flexible: PLA soft, TPE / TPU
- Clean
- simple-to-use
- office-friendly
- Potential for the production of Complex geometries and cavities
- Controllable parameters
  - Extruder temperature
  - Platform temperature
  - Printing speed
  - Layer height
  - Layer Printing direction
  - Extrusion width
  - Z-Distance

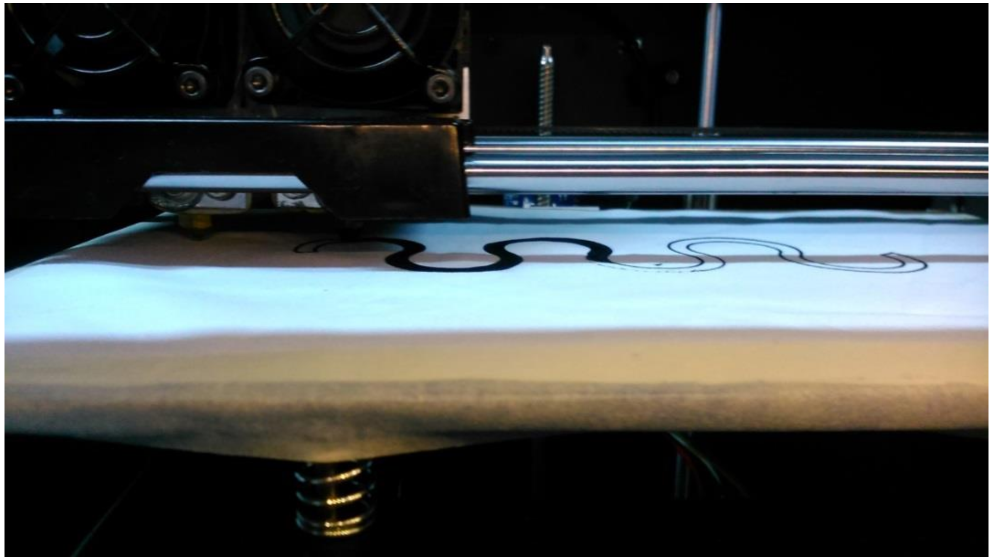


J. W. Stansbury and M. J. Idacavage, Dental Materials, 2016, vol. 32, no. 1, pp. 54–64.

Proposed Technology: FDM 3D printing on Textile



CAD modeling



It is believed 3D printing on textiles can be one of the solutions to open up opportunities and fulfill the requirements of functional and smart textiles such as cost and flexibility as a more flexible technique.

The workflow of the method begin with a CAD modeling and then the design is given to 3D printer and as you can see in the figure you can have polymeric patterns on certain places of fabrics for example to integrate printed sensors and interconnections.

R. Hashemi Sanatgar, 'FDM 3D printing of conductive polymer nanocomposites : A novel process for functional and smart textiles', PhD dissertation, Högskolan i Borås, Borås, 2019.

Potential Benefits of 3D Printing on Textile

- The technology can be applied where patterned and water and solvent-free functionalization is needed.
- The technology enables to improve the ecological footprint by minimization of textile waste as well as reduced consumption of energy, water and chemicals.
- The technology is high productive, flexible and cost effective
- It has short time to market for textile innovations.
- It is adaptable to quick changes of customer demands.
- It is possible to develop innovative products for functional and smart textiles

Main challenges of 3D Printed Textiles

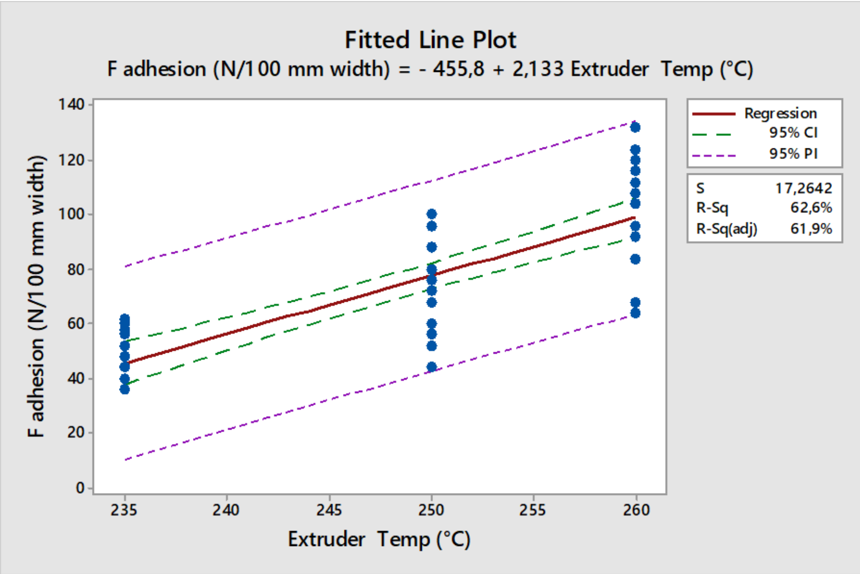
- Durability
- Flexibility
- Comfort

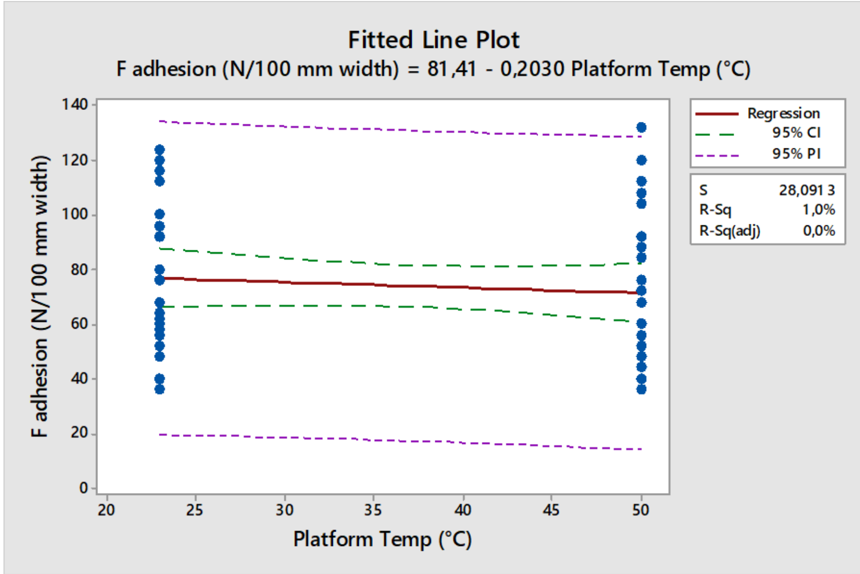
Affecting factors on 3D printed textile properties

- Adhesion
- Tensile properties
- Bending and drape properties
- Washability
- Abrasion

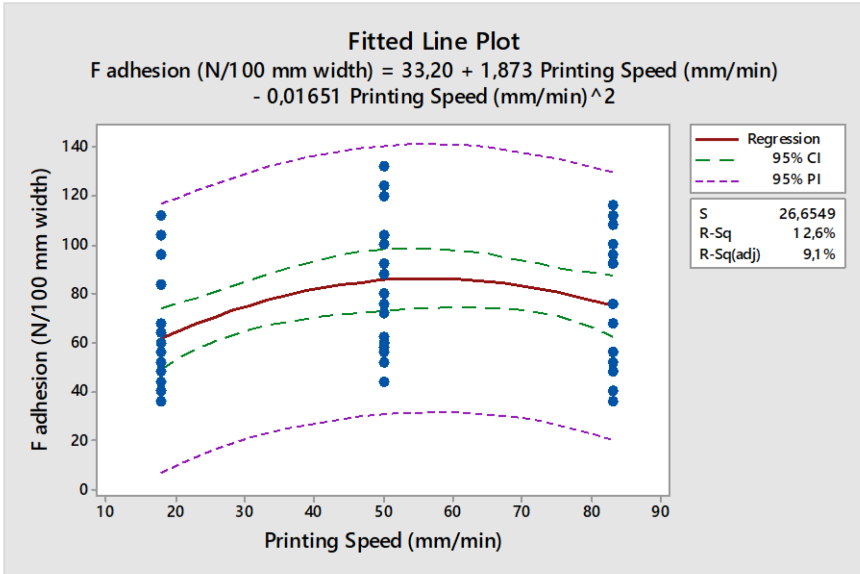
R. Hashemi Sanatgar, 'FDM 3D printing of conductive polymer nanocomposites : A novel process for functional and smart textiles', PhD dissertation, Högskolan i Borås, Borås, 2019.

What is the effect of FDM process parameters on the adhesion properties of 3D printed polymers on textiles?





- Adhesion force versus extruder temperature has a linear regression model and P-value is less than 0.05 which means there is a significant linear effect of the factor extruder temperature on adhesion.
- Since the platform temperature (23 and 50°C) was chosen not higher than the glass transition temperature of PA6.6 fabric (Tg=55°C), there is no significant linear effect of platform temperature on adhesion force.
- There is a significant quadratic effect of printing speed on adhesion force. Printing speed in middle ranges (50 mm/min) causes the highest adhesion results.

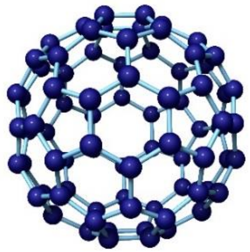


Sanatgar R.H., Campagne C., and Nierstrasz V. Appl Surf Sci 403: 551-563, 2017

Nanomaterials-based additive manufacturing

Could a combination of nanomaterials and additive manufacturing offer new opportunities in nanocomposites?

The union of the technologies could offer advantages as below:



0D - Fullerene

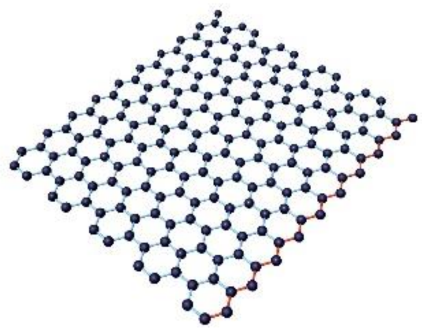
1D – Carbon nanotube

Nanomaterials

- Manipulation of fundamental properties

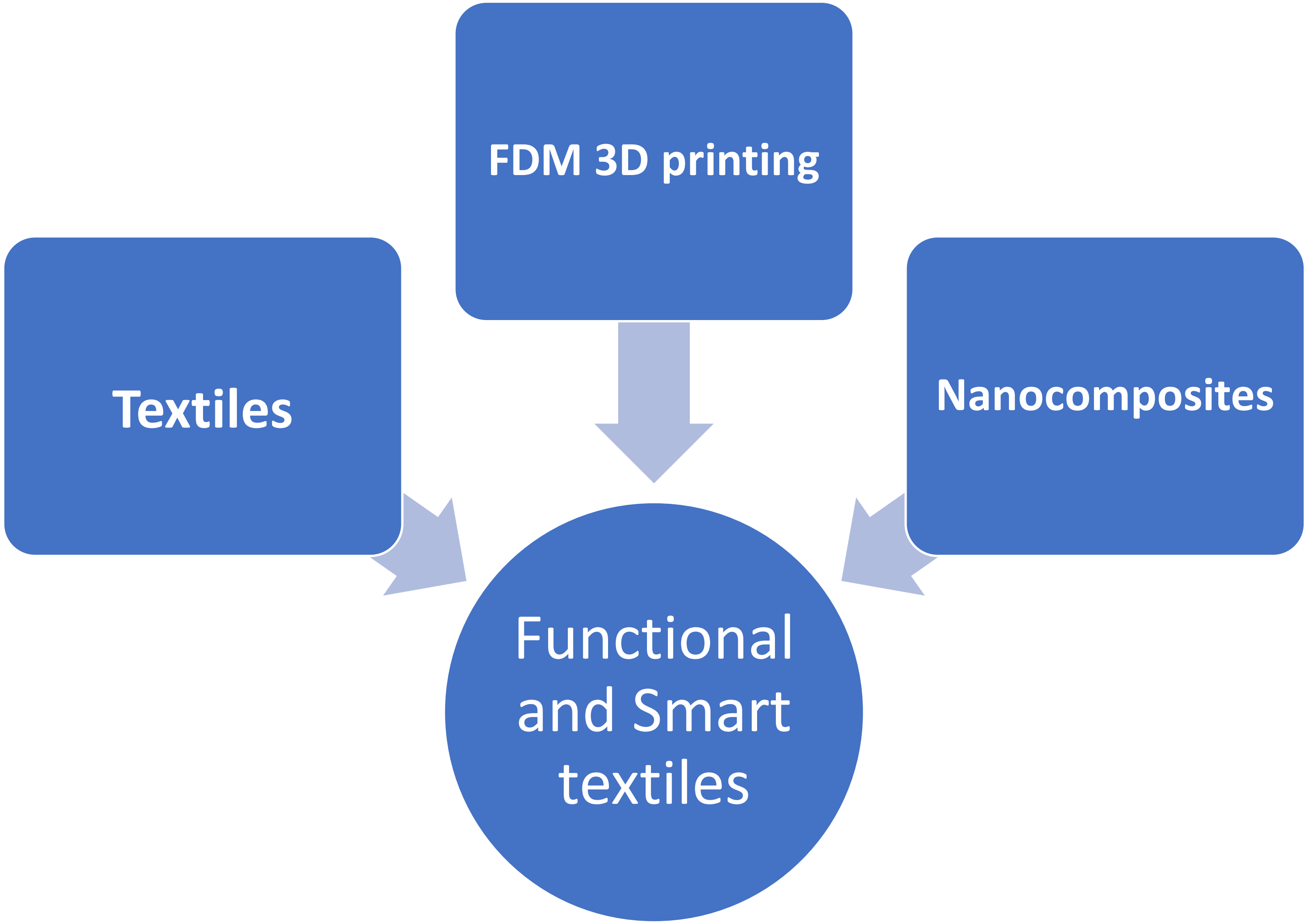
Additive manufacturing

- The Customized geometries,
- Reduced delay between design repetitions
- Single tool production
- Increased parts integration



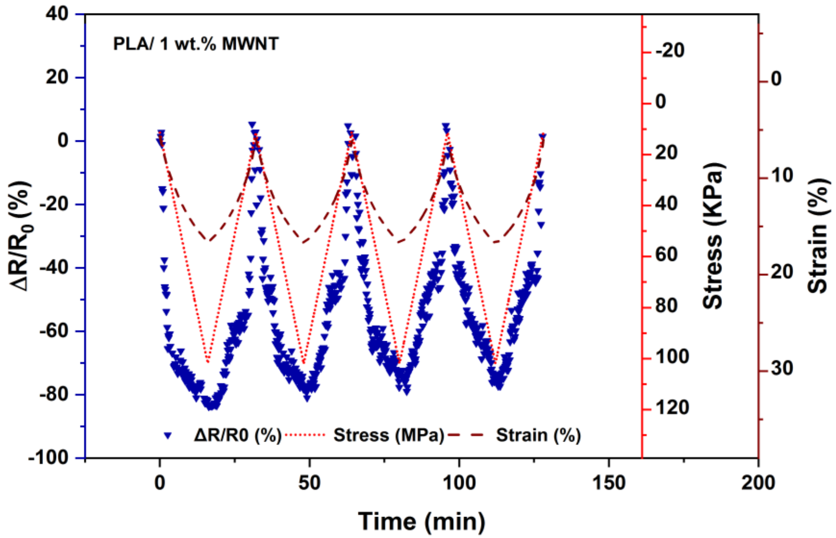
3D - Graphene

T. A. Campbell and O. S. Ivanova, Nano Today, vol. 8, no. 2, pp. 119–120, 2013


FDM 3D printing
Textiles
Nanocomposites
Functional and Smart textiles

Towards pressure sensor application:

Piezoresistive behavior of 3D printed PLA/1 wt.% MWNT nanocomposite in cyclic compression mode



10 to 100 kPa pressure range:

- **Sensor gloves** to monitor hand stress during manual activity and object manipulation
- The **foot pressure** due to the body weight
- The **tennis racket** with repetitive motions

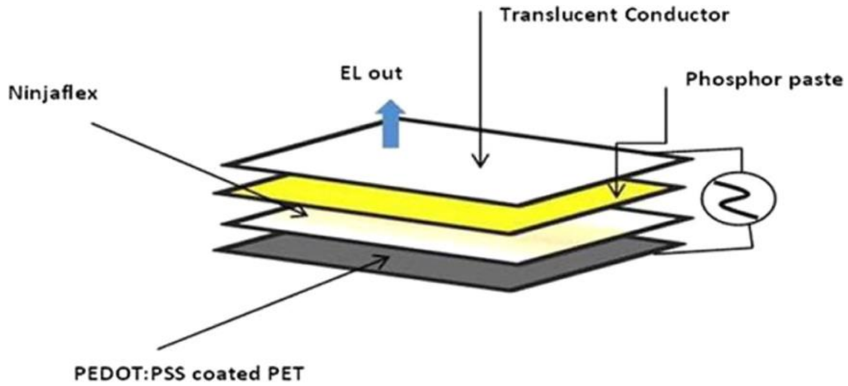
- Gauge factor G = 7.6
- Piezoresistive response A_r = -0.8 (-80%)

R. Hashemi Sanatgar, 'FDM 3D printing of conductive polymer nanocomposites : A novel process for functional and smart textiles', PhD dissertation, Högskolan i Borås, Borås, 2019.

Electroluminescence application:

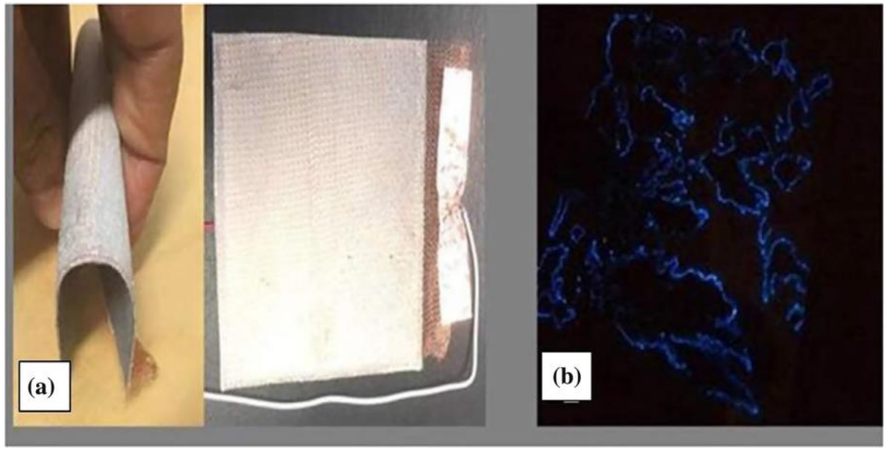
3D Printing of NinjaFlex Filament onto PEDOT:PSS-Coated Textile Fabrics

Electroluminescence device fabrication method



- Good adhesion
- Good washing
- Flexible to be integrated into textiles

Electroluminescence (EL) is the property of a semiconductor material pertaining to emitting light in response to an electrical current or a strong electric field. The purpose of this research is to develop a flexible and lightweight EL device.
PEDOT:PSS—with ethylene glycol (EG) was coated onto polyester fabric where NinjaFlex was placed onto the coated fabric using three-dimensional (3D) printing and phosphor paste, and BendLay filaments were subsequently coated via 3D printing. The prototype device emitted light with a 12-V alternating current power supply.



Prototype of (a) EL device and (b) EL.

M. TADESSE, et al. Journal of ELECTRONIC MATERIALS, Vol. 47, No. 3, 2018

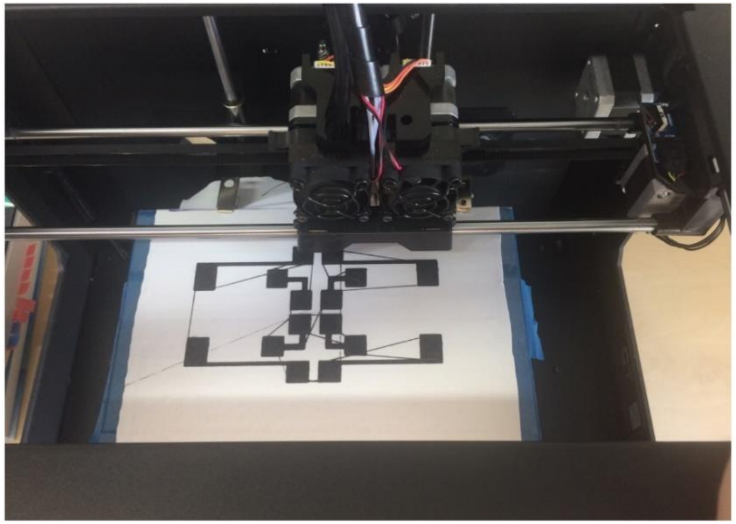
Towards electrodes application:

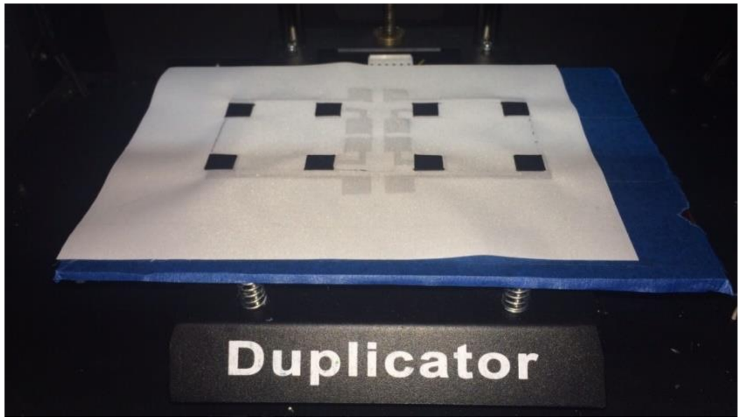
Surface electromyography (sEMG)

- **sEMG monitoring** has promising applications within the field of **human robot communication** where wearable EMG electrodes for measuring electrical activity of muscle contractions are used as the interface.

- Electrically conductive and flexible filaments of **thermoplastic polyurethane** containing **carbon black** and **polyester** fabric as substrate.

- **Less number of deposits** resulted in **lower volume resistivity**
- **Post treatments (heat and pressure)** improves the performance in comparison with standard electrodes.

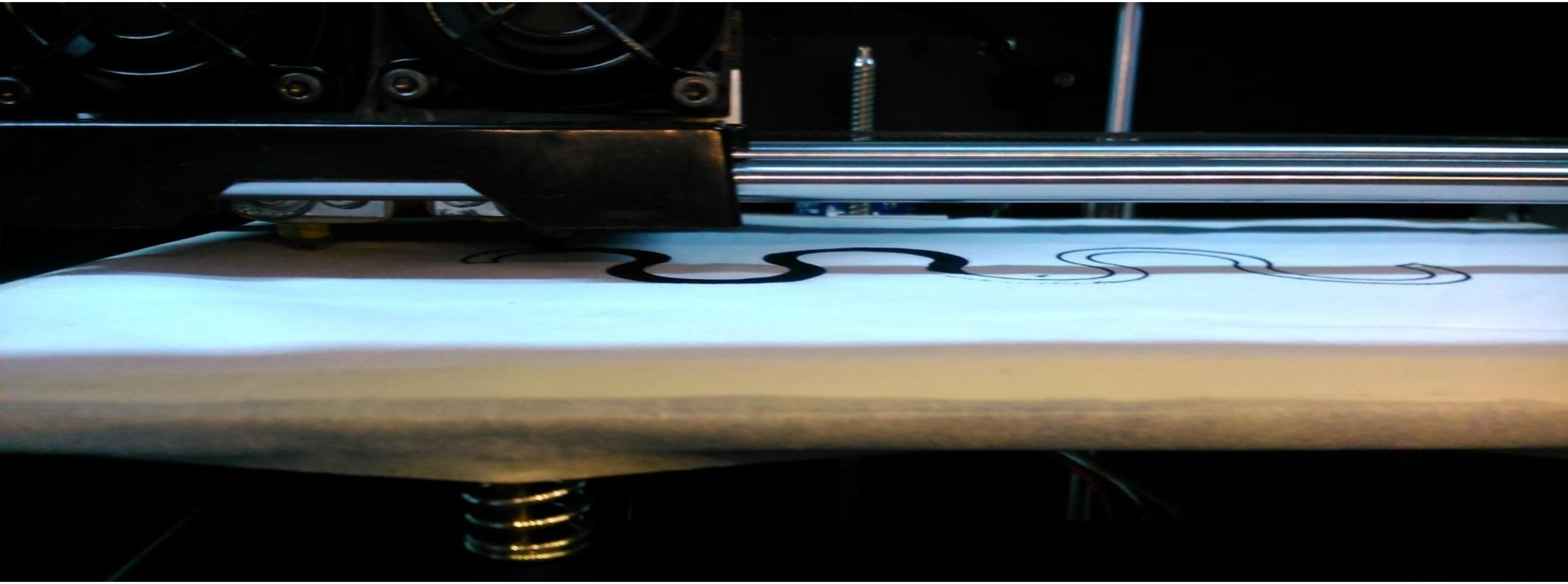

3D printed electrical circuitry



EMG electrodes

V. Malm, et al. IDTechEx Show! Berlin, April 11-12, 2018

Visit http://destexproject.eu/ to see the rest of the intellectual outputs of the project



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