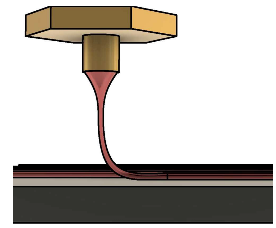
Sep 10, 2024



Towards standardisation of parameter reporting for melt electrowriting

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Protocol status: Working
We use this protocol and it's working

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Abstract

This protocol aims to help researchers collect all necessary data to make their research in melt electrowriting more reproducible and easier to compare to the data of others.

Image Attribution

Guidelines

As there is no standardised way of reporting parameters for melt electrowriting yet, this protocol aims to help with the standardisation (see King & Bowlin, 2021). Hence we recommend following all the steps and reporting them in the corresponding publications along with the results.
The data points resulting from the steps under the section named "Printing information" should be collected before every print and stored as digital record safely. For publication, the printing information of the constructs used should be made public.

Materials

- Melt electrowriting machine (commercial or self built)
- Differential Scanning Calorimetry (DSC)
- Thermogravimetric Analysis (TGA)
- Scanning Electron Microscope (SEM)

Safety warnings

In addition to the already substantial and often underappreciated dangers of building and modifying a 3D printer, which involves mains voltage wiring and manually installing and configuring hundreds of watts of electrical heating power into a small box, melt electrowriting (MEW) further introduces a high voltage hazard in the same printer. We thus ask readers to be mindful of these risks and to heed the warnings outlined in the official Voron manuals as well as the following information on safely interacting with high voltage for MEW.
Melt electrowriting requires an electrical potential in the low Kilovolt (kV) regime, and a properly designed system can achieve this easily while operating at below 10 Microamperes (μA) of current. Due to availability, the most used high voltage power supplies have a maximum output of approximately 10 kV and 1 mA, but have their maximum current output reduced to 1% (10 μA) for safe operation in case of arcing or electric shock. Since we anticipate readers to build and experiment with these machines, we ask the readers to err on the side of caution and inform themselves thoroughly based on their specific high voltage sources of the dangers and intricacies of their specific setup before they implement their ideas in practice, and consider safety interlocks, warning lights and proper signage an essential part of their experimental work.
Warning taken from the SI of "MEWron: an Open-Source Melt Electrowriting Platform" (https://doi.org/10.1016/j.addma.2023.103604)

Device information (Per device/configuration used)

1 If your system has been published before, make sure to add a reference to it, otherwise share a build guide or what modifications to published systems have been made as done by Eichholz *et al*. 2022 or Reizabal *et al*. 2023.

2 Note the type of extrusion used. Examples are syringe pumps, pressure-driven systems or extruder based systems.

3 Note the configuration of the high voltage (HV) system. Where is the HV applied, which field direction is being used.

4 Note which parts of the printer are moving in which direction(s). While a static collector with a moving head, and a moving collector with static head should produce the same results, there might be differences observable.

5 Note the collector specifications. Is it flat, tubular, or different? What is the material of the substrate that is being printed on?

Printing material information (Per material)

6 The supplier should be named for every commercially available material .
If the material is selfmade, the synthetic route should be added or referenced. For blends, a detailed description of the production process should be made available.

7 Note name and chemical composition.

8 Note molar mass (and dispersity) if known.

9 Note any pre-treatments prior to printing (storage under Ar, at XYZ °C,...).

10 Note the grade of the polymer (commercial grade, medical grade,...). This is especially needed for materials intended for biomedical applications.

11 Note melting, glass transition, and recrystallisation temperature (if known), ideally obtained via DSC.

12 Note stability at melting or printing temperature, ideally obtained via TGA.

13 Take an image of the jet formed at the nozzle.

G-Code information (Per code)

14 Each code should be made available in full.

15 If the code was created using a G-Code generator, it should be made public as well or cited if that has been published before (like Devlin *et al.* 2024).

16 The code should be written without complicated language that might not be replicated on all machines like "for" loops or similar code. Device specific code can of course be used but should be commented so users with different machines can understand it and adapt it to their systems.

17 In the beginning of the code important parameters, especially the print parameters (see printing information section), should be defined.

18 Furthermore, layout (flat/tubular, angle, number of layers) and number of scaffolds should be stated.

Printing information (For every print)

19 Note ambient temperature and humidity (°C, %RH).

20 Note time and date (YYYY-MM-DD, hh:mm).

21 Note nozzle diameter (Gauge or mm).

22 Note collector-nozzle distance (mm).

23 Note HV (field orientation and strength, kV).

24 Note material.

25 Note reservoir temperature and collector temperature (if applicable, °C).

26 Note flow rate/applied pressure/extrusion rate. This should ideally be given in µL/h or nL/h. Pressure should be given in bar (if PSI is being used, conversion should be made in text but original value also stated).

27 Note relative collector speed (ideally in mm/min).

28 Note duration of print (estimated).

Fibre information (for every print discussed)

29 Fibre diameter should be measured via SEM in a standardised way across all printed constructs. To avoid human influence, ImageJ plugins such as GIFT can be used. Fibre diameters should be reported with standard deviation, number of measurements (n) and number of scaffolds (N).

Software

ImageJ (Fiji)	NAME
Windows 10	OS
National Institutes of Health (USA)	DEVELOPER
https://imagej.net/software/fiji/downloads	SOURCE LINK

30 Note inter-fibre spacing and determine the lowest possible per material (if new material).

31 Note maximum layer height achieved per material.

32 Show representative SEM images (with scale bar) showing also the defects if present (bridging/gapping, bad stacking, pulsing,...).

33 Compare fibre diameter to expected result (if applicable).
Show analytical/theoretical validation.

Protocol references

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