Quick Insight Brief: Directed Energy Deposition-Additive Manufacturing

RESEARCH QUESTION

Does the directed energy deposition-additive manufacturing (DED-AM) process fit into the production of components for the nuclear industry, and, if so, when will the technology be available for the industry?

KEY TAKEAWAY

In the not too distant future, DED-AM may be used for a variety of small to medium (less than 500 lbs. [227 kg]) nuclear component applications (for example, valves, fittings, pump housings, and reactor internals), or it could be used to supplement traditional manufacturing processes through buildup of nozzles or other attachments. Manufacturing with DED-AM may offer advantages of shorter component lead time and reduced inventory of spare parts or materials and should be available within the next four to six years.

KEY POINTS

- DED-AM offers deposition rates ranging from 0.5 to 10 lb (0.2 to 4.5 kg) per hour, with some systems and materials capable of up to 20 lbs. (9.1 kg) per hour, allowing small to medium parts to be readily produced.
- To date, DED-AM processes have not been qualified by the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code nor accepted by regulatory bodies. The Electric Power Research Institute (EPRI) is supporting development to generate a data package and Code Case for ASME qualification.
- Progress is being made toward enabling DED-AM use in the nuclear industry for components such as valves, fittings, pump components, and reactor internals.

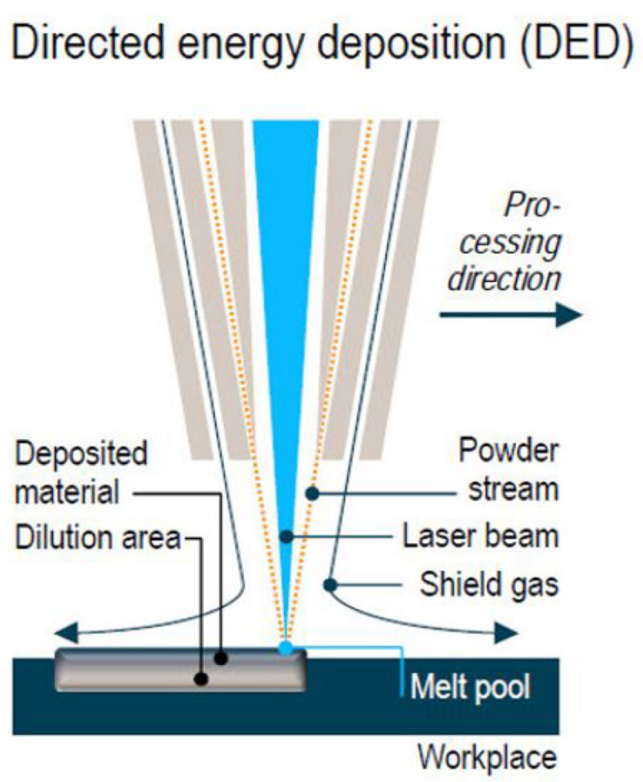
WHAT IS DED-AM?

Additive manufacturing (AM) is a novel fabrication technology that has generated significant interest across various industries (for example, automotive, aerospace, energy, and defense). Although polymer-based AM is significantly more mature, a notable effort is also being carried out to investigate and improve metal alloy AM technology. AM of metals offers the ability to produce net-shaped parts with a complexity that is not possible using traditional metal manufacturing processes, such as casting or forging. One of the key applications for AM that is being considered is the production of parts for replacing existing components/parts where potential cost advantages of reduced lead times or decreasing inventory of spares could offer a distinct advantage.

Looking to future designs, AM allows flexibility in part geometry that could be used to improve flow or thermal performance, and potentially for improved irradiation resistance through development of complex microstructure.

One of the metal AM processes, DED-AM, involves the use of a heat source and a feedstock (or filler) material applied together to deposit sequential layers one on top of another. DED-AM can be thought of as welding used to generate multiple layers and to manipulate those layers to build components. The heat source of DED-AM can be a laser beam, electron beam, arc, ultrasonic, or other that is currently under development. The feedstock material is typically wire or powder, but some applications may use foil or rod feed stock. Figure 1 shows a schematic of the laser DED process with powder feedstock that is blown into the melt pool. The laser beam, electron beam, and arc-based processes are the most applicable to parts currently under consideration for use in the nuclear industry. Welding and/or cladding with these same processes has been used for material buildup for decades, including construction of the existing nuclear power plants (for example, vessel cladding, turbine blade tip restoration, and rotor journals). The technology that has allowed DED-AM to progress beyond its conventional welding background is the software that is used to control the process. Advanced software that turns a solid model of the component into many slices (or layers) and improves control of the material deposition is a key enabler for DED-AM.

The DED-AM process has the advantage of high deposition rates and equipment that allows larger component sizes to be built compared with other metal AM processes, such as powder bed fusion-AM. Table 1 gives typical deposition rates for two DED processes in comparison to welding and powder bed fusion-AM. With the high deposition rate, DED-AM is feasible for producing parts that would not be economical



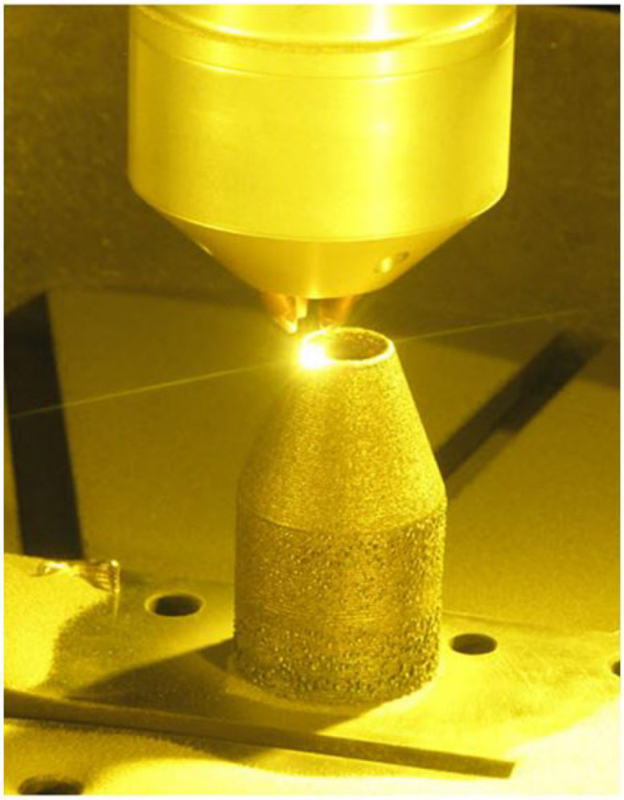


Figure 1. Schematic of the laser DED process with blown powder feedstock and picture of a nozzle in process [1]

with slower AM processes. Parts have been produced with DED-AM in typical structural materials on the scale of hundreds of pounds. Figures 2 provides examples of two valve bodies that have been generated to demonstrate properties. Mechanical properties such as tensile, impact, and hardness of DED-AM have been shown to meet or exceed those of the same type wrought materials [2]. Figure 3 shows a 7-ft (2-m) tall structural component produced with carbon steel using gas metal arc (GMA)-DED. The excavator arm was installed and used without failure in demonstration testing [3].

DED-AM could also augment traditional manufacturing processes for flexibility of the overall component production. Options could include buildups of nozzles or piping attachments onto forgings or creating raw material stock for further machining. One limitation of the DED-AM process is that it can typically only be deposited in the flat welding position; therefore, part manipulation to maintain the flat position is required for some part geometries. Overhanging geometry can be built, but it is limited to 15° off vertical without rotating the build [4]. Support geometry for overhangs is normally not employed because

Table 1. Deposition rate comparison

Process	Deposition Rate (lb/hr)	Deposition Rate (kg/hr)
LPF (single laser)	0.1–0.3	0.05–0.14
DED-AM, Laser (blown powder feedstock)	0.5–1.1	0.2–0.5
DED-AM, GMA	1–10	0.5–4.5
DED-AM, wire fed electron beam	7–20	3.2–9.1
GMA welding	2–15	0.9–6.8
Shielded metal arc welding	2–5	0.9–2.3

Figure 2. Valve cage in 316L stainless steel in process using GMA-DED, and cage and valve body after final machining
Used with permission from Best Engineering in Energy Solutions

Figure 3. A 7 ft tall excavator arm produced with GMA-DED in carbon steel, weighing approximately 290 lb (133 kg) [3]

removal would require machining and rotating the build to change the build direction eliminates the need for supports.

The potential to create unwanted defects in DED-AM builds is similar to that of welding. Porosity, lack of fusion, and cracking all must be considered when developing the process conditions to build a given part and implementing process control to ensure repeatable quality. The microstructure of DED builds must be considered, which can also vary depending on the heat input of the specific DED process that is used. Depending on part geometry, process, and material, a wait time between layers may be necessary to meet weld interpass temperature requirements. Productivity may be limited to ensure that mechanical properties, chiefly yield strength, are met. Higher deposition rates and heat input may also lead to limitations in producing fine features with DED processes, particularly compared with the laser powder bed fusion (LPF) process. DED processes may not be suitable for those applications or could require post machining. The corrosion resistance of DED microstructures relative to existing production methods also needs to be understood more fully.

WHERE WILL DED-AM BE USED TO MANUFACTURE NUCLEAR COMPONENTS?

DED-AM technology can be used to produce parts in the range of roughly 50–500 lbs. (23–230 kg). Parts less than 50 lbs. (23 kg) are likely better candidates for the LPF process. It is expected that pressure boundary and nonpressure boundary parts as well as structural components will be fabricated using DED-AM. Replacement parts identified as candidates for manufacture using DED include valves and fittings of the appropriate size. Potential reactor internal parts for DED include control rod drive components and dome cooling spray nozzles.

EMERGING ADVANCED MANUFACTURING TECHNOLOGIES

AM Focus Area

Collaborative efforts between EPRI's Advanced Nuclear Technology program and the Welding and Repair Technology Center are focused on enabling DED-AM for the nuclear industry applications. Current work includes investigating defect tolerance, nondestructive examination benchmarking, testing of demonstration parts, and supporting development of an ASME data package for 316L stainless steel. This work will support Code and regulatory acceptance of DED-AM in the near future. As the technology matures, developing procurement guidelines for DED-AM is also planned.

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