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A Thought Experiment

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- Additive Manufacturing Processes, 2020, Springer
- Additive Manufacturing Solutions, 2021, Springer
- Additive Manufacturing Classification, 2022, Springer
- Additive Manufacturing Advantage, 2023, Springer
- A new theory of additive manufacturing, 2024, Springer
- A concise encyclopedia of additive manufacturing, 2025, Springer
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Preface

The short book is presented in the form of dialogues between two researchers. They and their dialogues are invented. Their dialogues try to draw attention towards various aspects of additive manufacturing (AM), i.e., its organization, its shortcomings, and its various nuances as understood differently by laymen and different experts.

The use of imaginary dialogues, a form of thought experiments, is an established method for truth-seeking in science communication and pedagogy. This is the first time it is applied in AM. This is written for those involved in AM. The use of metaphors and narratives can make it useful also for those engaged in education. It can be especially useful for those who are experts in other fields but are interested in AM.

Gumla, Jharkhand, India
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Sanjay Kumar

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Additive Manufacturing Debate

Abstract

Two imaginary researchers, R1 and R2, start talking about hybrid additive manufacturing (AM). Their talk turns into a debate. None of them is less knowledgeable. One cannot teach the other. They are not interested in being part of a Socratic dialogue, where one assumes the role of a teacher, while the other becomes a student. They wonder whether both AM and hybrid AM are the same. Soon they discover that what they understand about the definition is far different than what it is. One says the definition has an inner contradiction; another defends it. One says the name of AM is not right; another shows the brighter picture. One argues that this name can have a negative implication on the education; the other questions the logic. Their discussion includes directed energy deposition, sheet lamination, powder bed fusion, other manufacturing techniques, pre-processing, and post-processing. One says sheet lamination is not AM; another shows how to make a product using sheet lamination. One says selective laser sintering should not be considered AM; another questions the way AM is getting compared with an established subject. At the end, there is no attempt to draw a conclusion; there are only viewpoints, logics, and arguments.

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Conversations

R1: What are you working on these days?

R2: I am working on hybrid additive manufacturing (AM).

R1: What is this?

R2: This is the combination of one AM technique with other techniques, such as machining (1) (2), forming (3), injection molding, forging (4) or other AM techniques (5).

R1: Why do you not do only AM?

R2: It is not enough. For technical reasons, when AM is combined with some other techniques, fabrication is more efficient. Or for economical reasons, when AM alone is expensive. I work on directed energy deposition (DED) (6) to create a special feature. The feature is created on a block that I machined before. Thus, I combine two techniques, DED and machining, to make a part. Since the part is not made by AM alone but by the application of AM and machining, I call the resulting technique a hybrid AM technique.

R1: You are mixing two techniques. Why do you not call it a compound or mixed technique?

R2: What is the difference between mixed and hybrid?

R1: A hybrid technique means you are creating a new technique out of two techniques, where two techniques have lost their identity or past behaviour to make a new technique. If your technique is not such a hybrid technique, better call it a mixture of two techniques.

R2: You are saying that two techniques lose their identity. Can you give an example?

R1: When you use cutting and electrochemical machining simultaneously, the impact of cutting force in the presence of electrochemical accelerates the machining. This acceleration makes the combination of two techniques a hybrid one (7). When they are combined, they do not behave in the same way when they are used one after the other. This is the loss of their past behavior or identity. When you sequentially combine machining and DED, whether you get the same acceleration in the action.

R2: Where did you get this knowledge about hybrid manufacturing from?

R1: It is a concept that says the combination of two manufacturing techniques be called hybrid only when the combination gives a drastic improvement in the result. It means when you add one and one, you should not expect that it will be two, but it should be more than two (8) (9) (10).

R2: But this is about machining. Why should I follow it when I am engaged in AM? Besides, it is not followable.

R1: Why?

R2: It says, as you already said, there should be a drastic improvement in the result. That is not always possible. That is not for all combinations of techniques. When two techniques are combined, the primary motivation is to get a product made or to remove the inefficiency of one technique with the help of another technique. The moment you bring a condition that the combination of two techniques will be called hybrid only when the combination brings a drastic improvement in the result, you are ignoring a number of techniques that are not combined for that purpose. Then, you are excluding many combinations from being termed as a hybrid technique. Do not mistake me. I am not against it if a combined technique gives a drastic result. But I am against making a hybrid technique a lofty goal that will be achieved only by a few.

R1: When you are already aware of what a hybrid technique should be, why do you call your combined technique a hybrid technique?

R2: If mixing of two techniques is accepted as a hybrid technique, then why should it be called a mixing technique? When I use ‘hybrid AM’ for the combined technique I use, it is because everyone uses the same name for the same type of combinations (11).

R1: Do you mean since everyone is using it wrongly, you are also using it wrongly?

R2: Please give me an example that will fit in an ideal hybrid AM.

R1: Should I create a hybrid AM out of two existing AM techniques?

R2: Please go ahead.

R1: Let us take the lower portion of a powder bed fusion (PBF) (12) machine. I mean the platform in which powder moves from one side to another side. Now, we have created half of a future machine. This is the lower portion of the future machine. We need an upper portion of this machine so it will be complete. We go and search for another AM technique so we will find the upper portion. Let us take another material jetting (MJ) (13) machine. Let us take its upper portion. I mean, let us take only its jetting system. Let us not take its platform where the jetting happens. Now, we have the jetting system of MJ as an upper portion of our future machine. Our future machine is complete, with its lower portion taken from PBF and its upper portion taken from MJ. This is a hybrid AM because it has been made from PBF and MJ, where PBF and MJ have lost their separate identities. You cannot take PBF out of this hybrid AM. If you try to snatch PBF from this hybrid AM, you will only have the lower portion of PBF, which will tell a story that once upon a time it was PBF. It will remind you that you have created the hybrid AM, not out of nothing. To create it, the contribution of PBF was taken, and the contribution of MJ was equally taken. But when the hybrid AM was created, there was no more PBF or MJ.

R2: Yes, a hybrid AM machine is created, but how will we use it?

R1: Do you not use it every day? Is it not the technique that you call binder jetting (BJ)? (14)

R2: Do you mean the upper portion of hybrid AM will jet binders instead of general materials, and the lower portion of hybrid AM will become a powder conveying platform?

R1: Yes.

R2: Do you want to say BJ is both AM and hybrid AM?

R1: Yes.

R2: I can also make another hybrid AM, like this. Let us take the lower portion of a BJ machine. It will be the lower portion of our future hybrid AM machine. We need the upper portion of our hybrid AM machine to make it complete. Let us search and find the upper portion. Let us take the upper portion of a DED machine. This upper portion consists of two parts: one part is for transferring energy, and another part is for transferring material. Let us choose only one part that transfers energy. Now, we have taken half of the upper portion of DED. This half part transfers energy; let us say it transfers laser energy. This one part becomes the upper portion of our future hybrid AM machine. Now, our hybrid AM machine is ready, which has an upper portion that transfers a laser beam. And its lower portion is present for conveying the powder. Do you agree that this is a hybrid AM machine?

R1: Yes.

R2: Is this not an AM machine that we call laser PBF? Just tell me whether PBF is an AM or hybrid AM. Do you remember where our discussion

R1: Do you mean you never apply a uniform coating using DED?

R2: I apply. It happens when some customers want their parts to be uniformly coated. But this is not what comes under the development of a hybrid AM process. This comes under customer service, which is the post-processing of a part. When we apply a non-uniform coating, as happened in an aluminum block, we do not call it post-processing.

R1: Do you mean when you apply a non-uniform coating on the aluminum block using DED, it is not post-processing?

R2: It is a post-processing in the sense that it comes after machining. Since machining is a process, a process that is coating that comes after machining automatically gets the right to become post-processing. But still it is not post-processing, because in AM, a process denotes a zone only where a shaping takes place. Post-processing is reserved for those techniques that come after the shaping is finished. Post-processing in AM is not supposed to interfere in the shaping. In a hybrid AM process, shaping happens due to the contribution of both machining and DED. When the first process, i.e., machining, is done to contribute to its share of shaping, the shaping is still not finished. The shaping is waiting for the second process, i.e., DED, to come and give its share of contribution. Unless shaping by DED is done, our combined process is not finished. Unless our combined process is finished, how can a post-process start? If we call the shaping by DED post-processing, we reduce the shaping by DED to

R2: No, it is not hybrid AM as well. Because for being a hybrid AM, one of the processes must be AM. When you create a shape by machining, one of the processes is machining. When you join them layer by layer, let us say by welding, then it is not AM. Because joining in AM is meant to create shape. Therefore, another process besides machining that you are using is not AM but joining. Therefore, sheet lamination is neither AM nor hybrid AM, but it can be a combined technique consisting of machining and joining. If you define this combined technique as hybrid manufacturing, it is hybrid manufacturing.

R1: Why are you saying, 'If you define…'? Do you want me to create a shape and define it as well?

R2: What I want to say is that it is a combined technique. I want to insist that it is a combined technique. A combined technique can be defined in many ways. Someone can say it is hybrid manufacturing, while others can say it does not fulfill the criteria of hybrid manufacturing. Some people can say it is special machining, while others can say it is special joining. When I say as far as defining is concerned, you are free to define it however you want, because your way of defining must not dilute the fact that sheet lamination is neither AM nor hybrid AM.

R1: What if I do not take pre-machined sheet metals, but I create shape layer upon layer by machining during the process stage? Is it AM?

R2: Then again, sheet lamination is neither AM nor hybrid AM. Because when you do layer upon layer machining and create shapes, you are creating shapes

without applying the method of joining. Though you are engaged in layer upon layer joining, this joining does not create shapes but sustains the shape created by machining. Just holding the shape created by some other method is not equal to creating the shape by joining. Since shaping is not done by joining, sheet lamination is not AM. The absence of AM and the presence of two techniques, i.e., machining and joining, make it a hybrid manufacturing technique.

R1: Can you suggest which type of sheet metal processing we should do so that we can have AM?

R2: The relation between sheet metal and AM is similar to the relation between the North Pole and the South Pole; they are not meant to meet. As long as there will be sheet metal, there will be no AM, and vice versa. Sheet metal is incompatible with AM. A sheet metal has only one use in AM: to become a substrate.

R1: Should I explain how to create AM products from sheet metals?

R2: Please go ahead.

R1: I take a number of rectangular-shaped metallic sheets. I keep them on a platform, one layer upon another layer, and join them by welding. At the end, I do not have thin sheets any more; they all have been joined to make a thick rectangular part. It is an AM product. This follows the principle of layer upon layer joining. Do you agree?

R2: No, it is not an AM product. AM is for the creation of a shape. You are not creating any shape. Though, you are making a thick rectangular part. But

represents one technique, and PBF represents another technique. If these two techniques are covered, then please be assured that the whole AM is covered. Please don't worry about any other techniques.

R2: But, these techniques are not "layer upon layer" but "usually layer upon layer." What is the difference between "layer upon layer" and "usually layer upon layer"? Does "usually" mean there was less confidence in AM when the definition was made?

R1: "Usually" means AM is a layer upon layer technique. But if a technique does not follow layer upon layer methodology and claims to be AM, its claim cannot be denied. For example, two-photon polymerization is not a layer upon layer technique but is AM.

R2: Does not "usually" dilute the definition?

R1: It dilutes. But what if it is strict? Creating a definition is easy, checking who uses it in which way is difficult.

R2: You want to say that since there is no benefit in having a strict definition, therefore a definition must not be questioned or updated.

R1: This thing I am not saying. I am saying that creating a definition without having an ability to control its use is not effective.

R2: Do you think the name of AM should be changed? (27)

R1: Why?

apply heat, these atoms move. Though when the particles are kept adjacent, there remain gaps between these particles. The moving of these atoms is called diffusion. When they cross the boundary, they start filling the gap, and a neck is getting formed between two particles (28). When the gap does not exist, we say our job is over. If we increase the temperature, there is a chance that melting can occur. That is why we need to be cautious that by whatever means we want to achieve sintering, we should not inadvertently cause melting.

R2: It is the principle that you are talking about. Please tell me how many times you have made sure that there should not be any melting when you work on an SLS machine. Do you have the means to make sure? Do you have enough experimental parameters to make sure? Do you have a machine that gives a guarantee that every particle that you will use will not undergo any sort of melting?

R1: It is the product that matters. Is it necessary to control each particle, when without controlling every single particle, we can fulfill the product requirement?

R2: Are you sure you never melt particles? Why do you use the word sintering when some particles melt?

R1: Sintering includes partial melting (29).

R2: But when you explained sintering, you did not include partial melting. Why do you not call selective laser partial melting instead of selective laser sintering?

R1: What if I call it selective laser sintering?

R2: Then, you should not call it AM.

R1: I work according to the definition of AM. I fulfill all the criteria that the definition expects me to fulfill. Since I fulfill the definition, it is AM.

R2: Fulfilling the definition is not a sufficient criterion to be AM. Your technique, i.e., SLS, needs to come under some AM category. Please tell in which AM category your technique comes.

R1: It comes under PBF.

R2: How can SLS come under PBF? PBF implies fusion, as it consists of fusion. Fusion means melting. You have just said SLS does not involve melting. Therefore, SLS has no category to be part of, which makes SLS a non-AM technique.

R1: Where it is written that it needs to come under some category?

R2: Is it possible to accept a chemical element as a chemical element unless it is part of the periodic table?

R1: Do you want to say that the periodic table of chemistry is equivalent to the classification of AM and chemical element of chemistry is equivalent to a technique of AM? Is it logical to compare a developing subject, like AM, to be compared with an established subject, i.e., chemistry? It is too early to compare and make an opinion.

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