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CSAM

Cold spray additive manufacturing

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Bachelor's thesis

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Style of the abstract is **Abstract**.

Cold spray additive manufacturing is a solid-state deposition technique that has evolved from a coating technique to a viable additive manufacturing method. It uses heated gas, like helium, nitrogen or air to accelerate particles towards a substrate material. The particles adhere through plastic deformation, so the thermal effects on the underlying material are minimal, which makes the process ideal for thermally sensitive materials. Some of cold spray additive manufacturing’s advantages are the unlimited build size, process portability and the ability to work on highly reflective materials. It faces challenges when it comes to the dimensional accuracy of the parts manufactured and the material properties of the parts manufactured. Its ability to manufacture alloys has made it lucrative for various industries such as the aerospace industry. When compared to other popular additive manufacturing techniques such as laser powder bed fusion and laser directed energy deposition, it stands out with its portability and minimal thermal impact. It lacks behind with its dimensional accuracy and initial material properties, but these can be improved with post processing. Currently it’s a great choice for repair applications and with further research it could become a viable option in part fabrication.

Key words: CS; CSAM; AM; PBF-LB/M; LDED; HPCS; LPCS

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1 Introduction

Cold spray additive manufacturing is a solid-state material deposition technique. It works by using heated gas to accelerate metallic particles to high velocities. These particles impact the underlying material and form a new layer by plastic deformation. Cold spray additive manufacturing has risen in recent years in popularity in the manufacturing sector along with other additive manufacturing methods to rival conventional manufacturing methods.

Since cold spray additive manufacturing is still a new process in the manufacturing field, it has not found a place as an established manufacturing method alongside other more established manufacturing methods. The goal of the paper is to find the most appropriate use cases for cold spray additive manufacturing in industry, by analysing the process itself and comparing it to industry-leading processes, such as laser powder bed fusion and laser directed energy deposition.

Due to cold spray additive manufacturing’s recent introduction to the manufacturing industry, there is not much research that compares the process directly to other additive manufacturing processes used in industry. Partly due to this and the length limitations of the thesis, the thesis will focus on comparing the process to just laser powder bed fusion and laser directed energy deposition.

In the starting section of the paper, the research methodology will be discussed. After that the paper will focus on cold spray additive manufacturing and go through the process itself and discuss its current use cases. After that cold spray additive manufacturing is compared to other industry leading processes, and their differences are discussed. In the final part, the findings are to be analysed, and conclusions are to be made of cold spray additive manufacturing’s most rational use cases.

2 Methodology

The main databased used for the paper was Science direct. Some articles from other databases were also included, since when looking up the sources used in the articles in Science direct, not all of the source-articles were available in Science direct. The search terms used were mostly abbreviations of the processes, such as ”CSAM”. Keywords were used with these abbreviations when looking up more specific data, such as the materials properties on a single alloy.

The included papers were most written in between 2021 and 2025. Since there is constantly new research made into the process, especially into the material properties of parts manufactured via cold spray additive manufacturing the focus was on the newer research. There were some older papers included due to the fact that the basic process has stayed the same throughout the years.

The types of papers used in this paper were review- and research articles. Review articles were mostly used to gain knowledge of the general processes. Research articles were used to gain knowledges of the more technical data, such as data about the material properties of the deposits. When comparing the processes individual articles were used since articles comparing the processes together were non-existent.

The used papers were categorised into two categories. Papers for reviewing the cold spray additive manufacturing process and papers for comparing the cold spray additive manufacturing process to other additive manufacturing processes. When comparing the processes the goal was to compare cases where the material used, or the process used was the same.

3 Literature review

3.1 CSAM

3.1.1 What is CSAM

Cold spray additive manufacturing, CSAM, was developed as a coating method, but in recent times it has gained popularity as an AM technology [1]. It has risen in popularity as a repair and restoration method due to its ability to not alter the underlying material properties of the substrate. Also its ability to deposit various materials, ranging from aluminium to conventionally hard to manufacture materials, such as titanium and various alloys, has given it the opportunity to be used in a broad way [2].

Cold spray is a solid-state material deposition process. It was first researched in the 1950s but gained mainstream attention in the 1980s as a coating technology. Due to technical advancements to the technology, it has gained popularity in additive manufacturing applications. The principle behind cold spray is that high temperature gas, is being used as a propulsive gas to accelerate metal powder, the feedstock, to a high velocity, as shown in Figure 1 [3].

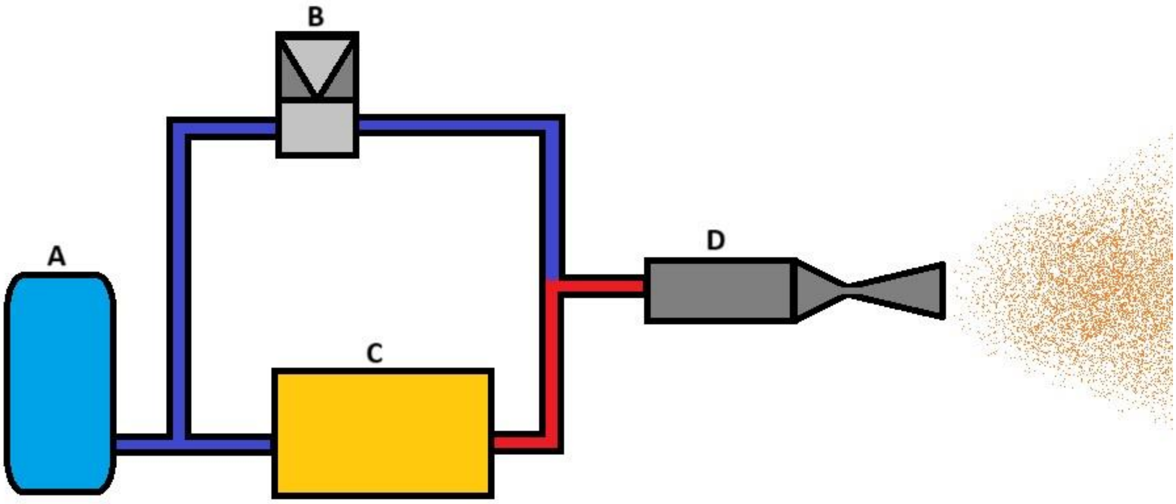

Figure 1. The gas is supplied by a gas supply, A, the powder is fed to the by gas by a feeding mechanism, B, the gas is heated up by a heating element, C, the hot gas with powder is accelerated by a nozzle, D.

The gas used in the process is accelerated to supersonic velocity by an often used converging-diverging de Laval type nozzle. The gas used in the process is nitrogen, helium or air. The powder is then fed to the flowing gas which accelerates the particle to a high velocity [4].

When this high-velocity feedstock powder impacts the base material, the substrate, the metal particles go through plastic deformation, at a temperature lower than the feedstock powder's melting point, at the substrates' surface and adhere to the substrate material, which is demonstrated in Figure 2.

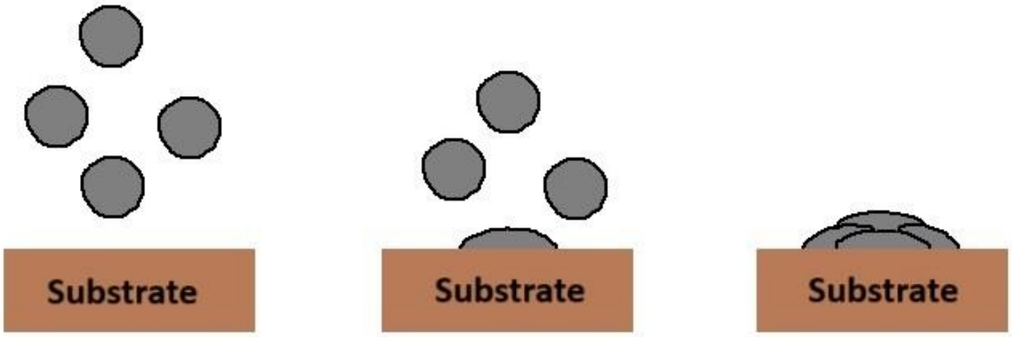

Figure 2. The adhesion mechanism is demonstrated in the picture. The particles impact the substrate and go through plastic deformation. The process advances from left to right.

Furthermore, the following particles create layers on the existing particles via kinetic compaction [2]. The ideal gas for the process is in most cases helium. This is due to the fact that with helium the powder feedstock can attain higher velocities when compared to nitrogen and air [5].

3.1.2 Advantages

One area that CSAM excels at is the manufacturing of high-reflective metals. Other AM processes that utilize lasers, have struggles when manufacturing components from e.g. copper or aluminium, due to the fact that the laser can reflect from the build material back to the optics of the laser, causing major damage. The lack of laser in the CSAM process make it ideal for these kinds of materials. Short production times, process flexibility and the many possible applications also are some of the merits of the CSAM process [2].

One of the biggest advantages of CSAM is the lack of heat in the process. Unlike other processes that melt the build material to the substrate, e.g. LDED, PBF-LB/M, the method of adhesion for CSAM being solid-state, allows it to be used on heat sensitive materials [2]. This has proven to be a big advantage for especially repair applications. The fact that the process doesn't produce nearly as much heat as other AM methods, means that the thermal effects on the repaired parts original microstructure are minimal. This means that parts that are under high stress applications for example in the aerospace industry, can be repaired via CSAM and if the parts material properties are sufficient the focus can be placed entirely on the newly manufactured part of the part, instead of the whole part.

The CSAM process is quite simple as the whole process can be broken down into four parts, that are needed for the process. These are a compressor, a gas heater, a nozzle and a powder feeder. The simplicity of the process allows it to be quite compact and thus very portable [3]. This is especially useful for repair applications since it makes onsite repairs a very viable option. This makes the process attractive for potential customers since the lack of need for disassembly and the need to send out parts for repair, cuts the downtime massively.

3.1.3 Disadvantages

One of the challenges with CSAM is the material properties of the parts manufactured. Parts manufactured by CSAM, usually have poor material properties out of the gate, so post processing is often needed. Parts manufactured via CSAM are sensitive to manufacturing parameters. Even variations in the part geometry when manufacturing parts that are not rotationally symmetrical can influence the material properties of the part [2]. One of the causes for these poor properties is the difficulty in controlling the process parameters. This is due to the fact that the feedstock powder is not uniformly sized. There are fluctuations in the particle sizes, and this leads to not every particle accelerating to the critical velocity needed. Also the inherent randomness of the process makes it unpredictable [5].

Another challenge currently for CSAM is the difficulty of obtaining the net shape of the part being manufactured. The traditional way of CSAM manufacturing is to move the nozzle in a zigzag pattern on the surface. This movement is done in the normal direction of the build surface. This way is good for building up the material, but it leads to geometric deviation of the desired geometry. To combat this, new techniques have been researched. One promising option is a technique called metal knitting, MK. The basic principle behind MK, is the angle of the spray and the movement of the nozzle in relation to the build surface. In the traditional way the nozzle is normal to the surface and does not rotate during the deposition process. With MK the nozzle is pointed on the surface at an angle, around 60 degrees and the nozzle rotates during the process. The MK process has shown to effect the material properties but the research regarding this topic is still minimal [6].

Furthermore, the fact that CSAM has only recently been introduced as a alternative to conventional methods for manufacturing, means that the amount of research that has gone into CSAM is minimal compared to conventional methods. Moreover the fact that CSAM was initially used for prototyping, means that the research that went into the process was not focused on the material properties of the parts [2]. Costs are also one of the considerations when it comes to the cons of the CSAM process. The ideal gas for the process, helium, is non-renewable and scarce, leading to its high cost, although a process to capture the helium gas and recycle it is being developed [5].

3.2 Use cases for CSAM

The flexibility of CSAM has allowed it to be used in different applications, the main ones being repairing and restoring damaged components and the fabrication of components, even with complex structures. Additionally, the process is still used for coating, which it was originally developed for. In the following chapters the focus is on these use cases and discussing them further.

3.2.1 Repair and restoration applications

In the mission for sustainability, CSAM has risen in popularity for its ability to repair and restore damaged components. Often damaged components could not have been able to be fixed and had to be replaced and disposed. CSAM’s ability to avoid thermal damage to the substrate material of the component being repaired and the ability for the powder to retain the properties of the feedstock powder, has made it ideal for restoring components to their original capabilities [3]. The three main applications can be summarized to corrosive and erosive damage repair, mechanical damage repair and damaged sheet metal restoration [3].

The method of repair is similar for all the cases. First the part being repaired has its surface prepared. This preparation usually involves the machining of the surface to get rid of the possible complex surface topography and after that the surface is polished. This allows for better adhesion for the feedstock powder [7]. After this the material deposition takes place. The part that is needed for the repair is back engineered by comparing the model of the original part to the damaged part, as shown in Figure 3.

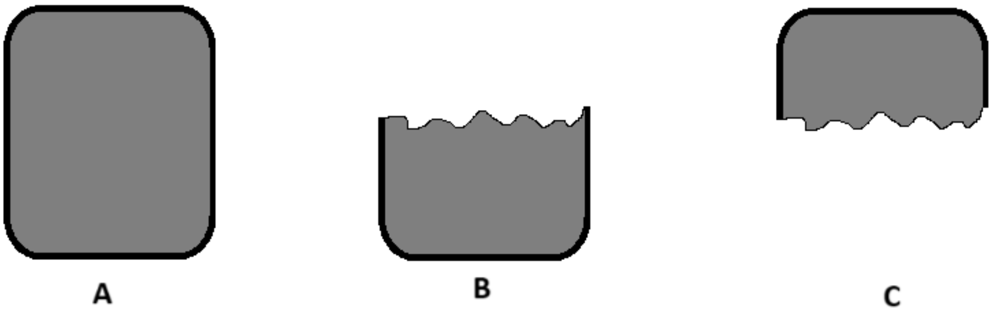

Figure 3. The original part A, is compared to the damaged part B. The subtraction of these parts C is then inputted to the machine as the part that needs to be built.

After the material deposition process, the part is transformed to its final shape with different post-processing techniques. This usually involves conventional manufacturing techniques like milling or grinding [3].

CSAM has shown a lot of promise in the aerospace industry in repair applications. CSAM has been shown to be able to repair components made of aluminium and superalloys to a standard where they have been able to be deployed back to service [3]. In general, CSAM was used in these cases used for dimensional restoration. The feedstock material can be of different material than the substrate, if the mechanical properties of the deposit are not of the biggest concern [5].

3.2.2 Fabrication of components

Free standing components manufactured via CSAM can be categorized into rotational structures and complex structures. Unlike some other AM-methods, CSAM is only able to produce rough structures, so often the produced components need machining or some other post processing to achieve the net shape or the surface quality required [3]. In industry use CSAM has mainly been utilized to manufacture parts with rotational geometry, due to the difficulties of manufacturing complex structures, for the reasons mentioned in the prior chapters [2].

For rotational structures often a substrate material, mandrel substrate, such as a metal pipe, is placed on a spinning spindle as shown in Figure 4.

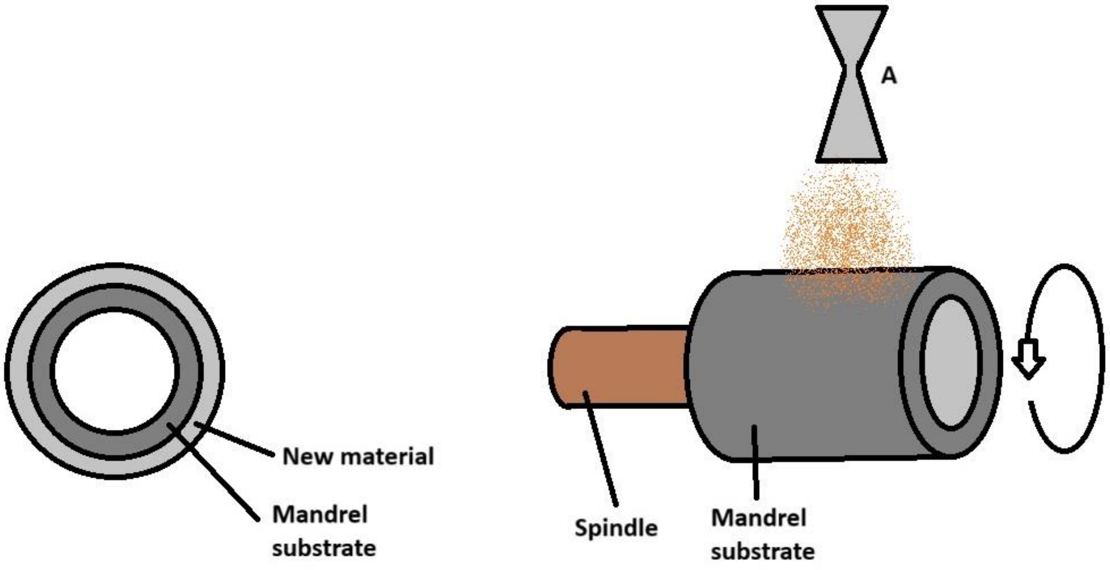

Figure 4. On the left is demonstrated the building of new material on the circular mandrel substrate. On the right, the spinning spindles principle is demonstrated. The nozzle, A, sprays the metal powder on the rotating mandrel substrate.

This enables the ability to manufacture rotationally symmetrical shapes with relative ease. A mandrel substrate is not always needed, and in some cases a sacrificial pipe can be used as the substrate. After the CSAM deposition process the pipe is removed from the fabricated component, usually via drilling and honing [3].

For complex structures, often subtractive manufacturing is needed along with CSAM to produce components. A specially designed substrate is used for the process since the ease of removal of the substrate, is a challenge in the process. With this process, existing components can be also modified. The process is very similar to repair applications, but instead of the original shape, a new shape can be manufactured to the component with depositing new material on it. This added material is then machined and thus even complex shapes can be added to existing components [3].

3.2.3 Coating applications

The ability of CS to be able to coat materials that are thermally sensitive and oxygen sensitive, due to its working principles, has given it a rise in popularity in this field. Due to its versatility, it has gained popularity aerospace, automotive and electronics industries [8].

Coating manufactured via CS, experience very little oxidization or decomposition during the process due to the fact that the feedstock powder adheres to the substrate below the feedstock powders melting point. However, even with below melting point adhesion, the coating is introduced to thermal effects that generate residual tensile stress. Compressive stresses are also introduced due to the impact deformation. Additionally, the major plastic deformation decreases the ductility of the coating. To combat these imperfections, heat treatment can be used to effectively change the microstructure of these coatings and thus improve the properties of these coatings [9].

3.3 Multimetallic CSAM

3.3.1 Multimetallic CSAM

As the name implies, multimetallic CSAM is the process of manufacturing parts or coatings that consist of multiple metals, better known as alloys. In theory if the metal alloy can be made into fine powder, it can be manufactured via CSAM. Obviously, there will be some practical limitations, such as the hardness of the metal particles. Since the method of adhesion is plastic deformation very high velocities and gas pressures might be required to accelerate the hard metal particles to required velocities [3]. Also, if the alloy contains particles of different hardnesses, the higher speed for the softer particles may lead to undesirable material properties.

One challenge that rises during multimetallic manufacturing is the appearance of satellite particles. Satellite particles are small fine powder particles that attach to larger rougher particles. This attachment is caused by collisions of the particles during the atomization process. As these satellite particles attach to other particles, larger particle deposits are created. These deposits may affect the powders flowability and the microstructure of the part created [10].

3.3.2 Multimetallic applications

A big market for multimetallic CSAM manufacturing is the aerospace industry. Many alloys and superalloys such as GRCop-14 and HR-1 are used in rocket engine applications due to their excellent material properties, such as heat resistance and corrosion resistance [10]. In a study deposits made of GRCop-14 and HR-1 were studied. The results showed that with the right parameters, such as choosing the accelerating gas correctly, low porosity and good mechanical properties could be achieved. Although in an untreated state the deposits exhibited not so good material properties when compared to conventionally manufactured counterparts. But these material properties, were able to be improved, with heat treatment, bringing the properties up to a standard where they could be used in, for example rocket engine applications [10].

In repair applications a lot of research has been done around Inconel for repair applications via CSAM. Inconel is widely used in the aerospace industry due to its high performance in high temperature applications. Since its used in rough environments, damage by erosion and abrasion are a large problem. Conventional repair methods have involved high temperatures and have resulted in undesirable microstructural effects on the underlying material. With its low heat input, CSAM has shown promise as a good alternative for conventional repair methods [1] [3].

Another big market for the multimetallic CS is for coatings. Tin bronze coating are widely used as an anti-wear material [11] and copper coatings are used for cases where high electrical- and/or thermal-conductivity is needed. In CS, aluminium oxide is often added to the copper to significantly improve the coating properties [4]. The use of CS in coating applications can be divided into two categories: low pressure cold spray, LPCS, and high-pressure cold spray, HPCS. In LPCS the gas pressure used is 0.5-1.0 MPa with particle speeds around 300-700 m/s and a gas temperature of 200-600 Celsius. For HPCS these values are 1.0-4.0 MPa, 300-1200 m/s and 200-800 Celsius. Of the two, LPCS is a more affordable option and due to the equipment’s portability is extensively used for coating and surface restoration applications [11].

3.4 Comparisons

CSAM’s recent rise in popularity as an additive manufacturing technology has exposed its advantages and disadvantages compared to other additive manufacturing technologies. In the following chapters, the focus will be on comparing CSAM to other additive manufacturing technologies. The current popular rivals for CSAM are laser powder bed fusion, PBF-LB/M and laser directed energy deposit, LDED, so most of the comparison are done between these processes. The focus will be on the material properties and the use cases but also the broader implications.

3.4.1 Material properties

One of the biggest talking points when comparing CSAM to other additive manufacturing technologies is the material properties. In this chapter, the focus will be on the material properties of Inconel 718, IN718, based parts, manufactured via CSAM, cold spray additive manufacturing, LDED, laser directed energy deposit and PBF-LB/M, laser powder bed fusion, since this is a common material between them [1], [12], [13].

When repairing IN718, traditional repair methods have involved high temperatures, that have affected the substrate’s base metal’s microstructure. With CSAM, when the particles are adhering to the substrate with minimal thermal effects and layers of particles are created. These layers are mechanically interlocked. This creates a base for the following particles to adhere to [1].

With LDED, extremely quick cooling rates can lead to undesired results, when looking at the microstructure. These undesired results can range from stress concentrations to even porosity and cracks on the surface. Due to the non-equilibrium microstructure and randomness of the grain growth on the substrate, the solidification microstructure of LDED manufactured IN718 alloys is always unique. This leads to the inability of using heat treatment processes used in traditionally manufactured IN718 alloy [13].

In the PBF-LB/M process a major concern on the material properties are distortion and residual stress. The cause behind this is the process of melting and solidification of the metallic powder. The distortion can lead to severe fluctuations in the dimensions of the manufactured part or assembly [12]. Like LDED, PBF-LB/M also has high cooling rates, which can lead to similar defects as LDED, such as porosity and cracking [14].

3.4.2 Use cases of repairing and restoration

When it comes to repairing and restoration, the methods looked at here are cold spray additive manufacturing, laser powder bed fusion and laser directed energy deposit. All these methods have the ability to be used in repair applications and part manufacturing, but the specific use cases differ somewhat. In this chapter the focus will be on the specific use case of repair and restoration between these processes and look into the possible limitations and available cases. [15], [14], [3].

The basic method of repair is the same for these three processes, building new material on the substrate. Beyond that the processes start to differ. Unlike CSAM and LDED, the size might become a limiting factor with PBF-LB/M, since the powder bed and the reach of the laser beam have practical limitations [14]. Both CSAM and LDED have in theory an unlimited build size since they both are able to build material directly to the substrate without the need for additional material, like the powder bed in PBF-LB/M [15], [3]. There will obviously be a practical limit with these processes too, but they are not as size sensitive as PBF-LB/M.

The method of repair with PBF-LB/M starts with the scanning of the damaged part. The damaged part is then compared to the original 3D model of the part, and the part used in the repair is reverse engineered. To start the repair process, a surface is prepared/created to the part being repaired. This is usually done by cutting a flat plane on the part which is then polished and used as the build surface [14]. Due to the inherent defects to the materials properties, post processing, such as heat treatment may be needed.

The method of repair with CSAM also starts with the modelling of the “repair part”. With CSAM the damaged part’s surface is also prepared to get a flat and polished surface to achieve the best adhesion. After the material deposition part, post-processing like machining may be needed on the part, if the dimensional accuracy is of importance, since with CSAM the surface is likely left uneven and larger than the original dimensions [3]. Also heat treatment can be applied to improve the material properties of the part.

The method of repair with LDED is quite similar to CSAM. A clean and smooth surface is needed but preparing a flat surface is not necessary [16]. Like PBF-LB/M and CSAM, LDED has its inherent flaws in the material properties, which makes post processing of the part with heat treatment a probable step [13]. Although these material properties can be influenced by different repair strategies, in the way of different pathing of the tool head [17].

What sets these processes the most apart, is the ability for CSAM to be very portable compared to PBF-LB/M and LDED. Unlike PBF-LB/M and LDED that need a lot of parts to function, CSAM is very a simple process compared to them. There are even handheld CSAM devices in industry, which would be impossible to repeat with PBF-LB/M and LDED. This makes onsite repairs very viable for CSAM, since the repair process itself takes very little time to setup. Especially repairs that don’t require great geometrical accuracy can be completed via CSAM very rapidly. When it comes to repairs that require fine geometry and detail, LDED and PBF-LB/M show their strong sides. CSAM lacks the pure accuracy that the other processes have, so to achieve fine detail and accuracy post processing, like machining of the repaired part, is a must.

3.4.3 Uses cases of manufacturing

With additive manufacturing CSAM suffers from the same inherent flaws as it does in repair applications. The mechanical properties of the deposits are lacking behind of those manufactured via conventional methods and the dimensional accuracy of the manufactured part is not great [18]. The method for fabricating components does not differ too much from repairing a component. Instead of using a broken component as the substrate, in fabrication a build plate is used. When it comes to complex structures, CSAM is often not enough by itself to be able to manufacture them, and conventional subtractive manufacturing methods have to be incorporated [3]. With CSAM the build size is also in theory unlimited so even large components can be manufactured.

With PBF-LB/M the dimensional accuracy is much greater than with CSAM. The final net shape can be achieved without the need for post machining [19]. Mechanical properties of the deposits are also a concern when it comes to PBF-LB/M. Due to the melting and solidification of the metal powder, residual stresses and warpage of the manufactured component is a concern [12]. These stresses and warpages are especially a noteworthy concern with complex structures with overhangs [20]. The build size is also a limiting factor when it comes to PBF-LB/M. The build size is dictated by the size of the build plate of the machine. For a typical PBF-LB/M machine the build area is limited to 250x250mm [21].

When it comes to LDED, it also suffers from poor dimensional accuracy. The mechanical properties of AM manufactured components is comparable to of those, manufactured in repair applications. The reason for this is the same as for PBF-LB/M, the melting and solidification process [13]. The build size for LDED is also basically unlimited since it doesn’t have a size limitation set by the build plate like in PBF-LB/M. Although the complexity of the LDED process when compared to CSAM might set some practical limitations to the build size [21].

When it comes to component fabrication, PBF-LB/M can generally manufacture the most accurate and the mechanically the soundest components. But this comes with the limitation of build size so larger structures are out of the question with PBF-LB/M. For larger structures in terms of build size and accuracy, CSAM and LDED are closely similar. They both can manufacture large structures but suffer from dimensional accuracy. When compared to PBF-

LB/M they both have worse mechanical properties for the components. The mechanical properties suffer from different reasons between them, so it’s hard to say which one’s flaws are better or worse and a better way to describe them would be different.

3.5 Tables/diagrams

Comparisons for repair applications in Table 1.

Table 1. Comparisons for repair applications for CSAM, PBF-LB/M and LDED

Process/function	CSAM	PBF-LB/M	LDED
Repair size	Repair size is basically unlimited. Practical limitations but not inherent limitations by the machinery itself.	Repair size is dictated by the available machinery. The size of the “build plate” is the limiting factor.	Repair size is basically unlimited. Practical limitations but not inherent limitations by the machinery itself.
Material properties	Minimal heat effects on the underlying material. Has inherent flaws in microstructure.	Heat effects on the underlying material. High cooling rates lead to undesired microstructure.	Heat effects on the underlying material. High cooling rates lead to undesired microstructure.
Preprocessing	A flat and clean surface is preferred for deposition.	A flat and clean surface is a must for deposition.	A flat and clean surface is preferred for deposition.
Postprocessing	Net shape of the part difficult to achieve, so postprocessing such as machining is needed. Heat treatment might be necessary for good material properties.	The net shape of the part can be achieved with great accuracy. Heat treatment might be necessary for good material properties.	Dimensional accuracy falls between CSAM and PBF-LB/M. Heat treatment might be necessary for good material properties.
Complexity	A simple and portable process, great for onsite repairs.	Requires a lot of parts to function. Disassembly required for repairing parts.	Also requires many parts. More portable than PBF-LB/M but less portable than CSAM.

4 Discussion and analysis

What CSAM excels at is the ability to deposit new material with inducing low heat. This is especially useful in repair and restoration applications, where the repaired part is manufactured from heat sensitive materials or when the heat effect to the part being repaired needs to be minimal. Because the adhesion mechanism is entirely mechanical in CSAM, it is ideal for highly reflective materials. Other AM processes such as PBF-LB/M and LDED require lasers to work, so highly reflective materials can prove difficult to manufacture for them since reflections are a big danger for the equipment and people.

An area where conventional manufacturing methods and other additive manufacturing methods still surpass CSAM is the manufactured part's material properties. When comparing the materials properties, the material properties of untreated parts manufactured via CSAM are lacking behind of the other methods. These material properties can be improved with heat treatment, but that adds time and equipment requirements to the manufacturing process. This is also one of the reasons why in repair applications, CSAM is used a lot for dimensional repairs, where the material properties don't play such a big role. Conventional methods also often can reach the desired dimensions with a single process, like milling, and don't require multiple steps in the manufacturing process.

The fact that that CSAM is an AM process, means that one-off parts can be manufactured without big changes to the equipment. Unlike conventional methods that may require big changes to things like moulds and jigs, just changing the process parameters is enough for CSAM. This opens the possibility for CSAM to be used in the bespoke part manufacturing area, since many manufacturers focus on manufacturing larger batches when using conventional methods. This drives up the cost for the parts orderer and may lead to wasteful use of the surplus material. Also, the fact that the build limitations for CSAM are in theory unlimited, means that large parts can be manufactured and repaired by CSAM.

With CSAM's current state the most sensible use case's fall into repair- and restoration applications and one-off part manufacturing. CSAM has shown much potential in repairing parts even composed of rarer alloys. Due to the relatively small amount of equipment needed for the CSAM process, on-site repairs are a big application for CSAM. The repair-industry is a lucrative market for CSAM, since in today's world the drive for sustainability, means that instead of replacing whole parts, repairing them is preferred. In the future this may lead to a big increase in demand for processes for repairing components. For part manufacturing, industries like the aerospace industry have shown a lot of interest in CSAM due to its ability to be able to manufacture components, like rocket engines, out of highly specialised alloys. The lack of build size limitations also means that for large scale components and structures, CSAM is a noteworthy option.

The biggest challenge currently for CSAM is the lack of research into the material properties of CSAM deposits. Compared to conventional manufacturing methods, the initial use of AM methods was focused on prototype applications, so it is lacking decades of research into the material properties, though the rise in popularity for CSAM has accelerated this research [2]. CSAM also lacks the dimensional accuracy that some other AM methods, such as PBF-LB/M possess. This means that alongside heat treatment, post machining of the part is often needed to reach the required dimensions. Research into this area is ongoing in the form of researching different deposition strategies. Techniques like metal knitting have shown some promise in to bettering the dimensional accuracy, but this area is lacking a lot of research and is an area that should be focused on more.

If improvements to the CSAM process will be made to be able to manufacture parts with better initial material properties and greater dimensional accuracy, the implications would be big. To get rid of the post processing requirements, would mean that bigger amounts of parts with good mechanical properties and dimensions could be manufactured much quicker. Also, currently for fabricating smaller parts, choosing other methods, such as PBF-LB/M make more sense due to its superior mechanical properties and dimensional accuracy when compared to CSAM. Research into manufacturing techniques that achieve greater dimensional accuracy are also being made [6]. If greater dimensional accuracy can be reached without compromising the material properties, a large chunk of manufacturing time will be cut out, with the removal of need for post machining of the part. This research is still new and scarce so further research is needed on this part.

5 Conclusion

The objective of the paper was to look at CSAM and find the most sensible use cases for it in its current state. What was found, was that CSAM has great potential to be used in repair applications, thanks to its ability to be able to deposit various metals and alloys on parts, without causing undesired heat effects on the underlying material. CSAM has also shown promise in fabricating free-standing components. Especially rotational components have been found to able to be manufactured via CSAM in great succession. Although untreated free-standing components may suffer from poor material properties, so post processing like heat treatment could be needed.

Since CSAM is a fairly new process in the AM-sector, there has not been too much research into its place in the manufacturing industry. Due to this it is significant to find the areas where CSAM currently excels at, since it is crucial for its research and development to be a noteworthy option when choosing the manufacturing method. Also identifying the areas where other processes still are the leading option over CSAM, show the areas where CSAM is still in need of improvement.

For future research, a look into improving the material properties by changing the process properties could bring even more advancement for CSAM especially in the free-standing component manufacturing area. Also, different techniques like metal knitting should be researched to find ways to improve the dimensional accuracy of the CSAM deposits. This would remove further steps from the process, since post machining wouldn’t need to be done to reach the desired geometry. This would cut a lot of time from the whole process.

CSAM has shown a lot of promise in the manufacturing sector to be used as a manufacturing method. Due to the manufacturing sector moving towards sustainable solutions, CSAM has risen as a noteworthy option for these needs. Further research is still needed to overcome some of the shortcomings of CSAM for it to become a mainstream solution, but the expectations for it are high.

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