Direct-to-Part Machining Waste Recycling using Laser Metal Deposition

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Abstract

Laser metal deposition typically uses metal powders as the build material of choice. The ability to reprocess waste materials using this technology would significantly reduce the material cost and cradle-to-grave energy content of parts produced using these methods. This capability will also greatly increase the utility of laser deposition to potential industrial uses. This paper explores the usage of machining chips as an alternate source of build material. Topics covered include material handling, material preprocessing, and comparison to powder-based deposition.

1 Background

Since its appearance, rapid prototyping technology has been of interest to various industries that are looking for a process to produce a part directly from a CAD model in a short time. Among them, direct metal deposition process is one of the few process which directly manufactures a fully dense metal part without intermediate steps. In this process, metallic powder is injected into a laser generated heat spot where the material is melted and forms a melt pool which quickly solidifies into metal layers [2, 3, 8]. Parts are built to completion layer by layer, from bottom to top. This process is similar to other rapid prototyping technologies in its approach to fabricate a solid component by layer additive methods.

Funded by the National Science Foundation and Air Force Research Laboratory, the University of Missouri-Rolla (UMR) has developed the Laser Aided Manufacturing Process (LAMP) [4–7, 9–13]. The system, illustrated in figure 1, combines both deposition and machining in a single setup. This eliminates part re-setup which is a significant advantage over processes which require post-processing in separate machinery.

Cost is a significant factor in delaying the proliferation of rapid manufacturing of metal parts. Not only is the capital equipment cost high due to the laser system, but the material cost has risen dramatically too. Steel, for example, has risen in price ten-fold in the last five years, as shown by the DOW steel price index in figure 2. Specialty materials, such as the powders used in laser based rapid manufacturing systems, are not exempt from this trend. In fact, the production of powder

Figure 1: The LAMP process during a repair operation - The laser cladding head is shown on the right. A touch probe head is currently held in the machining spindle. A repaired H13 tool steel die component is held in the vise.

requires additional shipping and processing beyond that of bulk steel, making the effect more pronounced. The solution to this problem, particularly in the case of hybrid material addition and removal proesses, is to re-use the waste material from the removal portion of the process. Particularly in the case of repair where some material is removed up front, this could reduce the processes' usage of the expensive virgin materials.

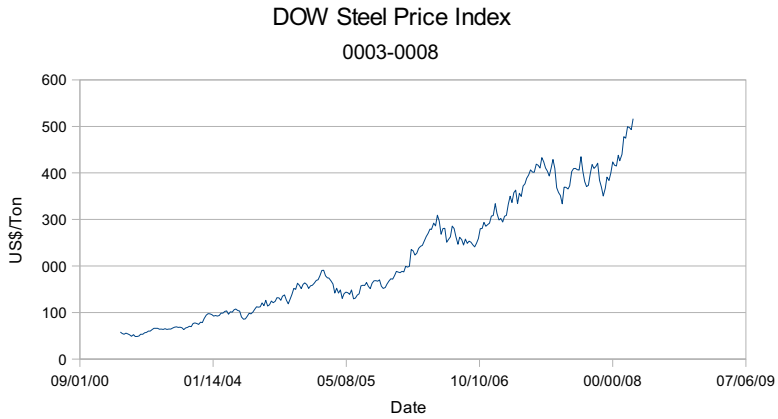


Figure 2: Rising Costs: The reality of doing business in America.

2 Considerations and Potential Benefits

Any production part will have a specification for both its geometric and mechanical properties. Microstructural characteristics are a major factor in determining the performance of a material. Solidification microstructure is a function of the material composition and the temperature gradient in both space and time [1,14]. For acceptable results, any attempt at using recycled materials will have to address contamination of machining waste.

From a broad enough view, any product is composed of three basic components:

- Energy - refinement of materials, manufacturing, transportation
- Materials - the stuff the part is made of, expendables in the manufacturing process that do not become part of the product
- Labor - design, manufacturing, transportation

Rapid manufacturing addresses the labor costs through automation. American manufacturing relies on automation and outsourcing to keep labor costs down. As energy costs rise, shipping costs rise, tipping cost scales back towards domestic manufacturing once more.

Even if powders used in a laser based rapid manufacturing system are produced from secondary materials, they still will have a significant cost of transportation from various entities in the supply chain (from the producer of the waste material, to a recycling facility, then to the powder manufacturer). Transportation costs are diffcult to generalize, however if reuse of on-site waste materials is possible, thus eliminating some transportation costs, a savings is clear. If the powders are atomized, then energy will have been spent melting the material in the production process as well.

3 Using Recycled Materials in the LAMP System

The LAMP system at MS&T cannot directly feed machining chips without modification to the existing systems. For compatibility's sake, a batch of Ti64 powder was produced from Ti64 machining chips. A deposit using the recycled powder was compared to a deposit made with virgin Ti64 powder.

3.1 Making Powder

A batch of Ti64 chips milled from a laser deposited part by dry machining were used in producing a batch of recycled powder. A ball mill, seen in figure 3, from United Nuclear was used to crush the chips into smaller pieces. Ceramic media was used in an attempt to minimize contamination of the powder. The progress of the milling operation can be seen in figure 4. At the end of the 990 minutes alloted for the experimental run of the ball mill, less than 50% of the material in the mill fit within the -70 +325 mesh spec needed for use in the LAMP system. Clearly a different method of refining the chips into powders is needed before this technique will be useful beyond the laboratory.

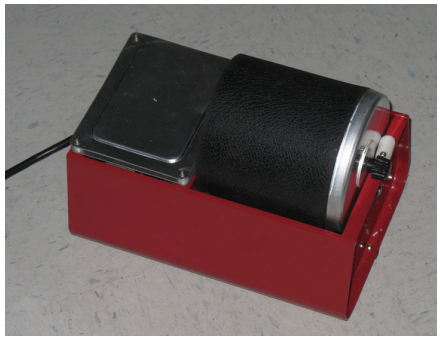
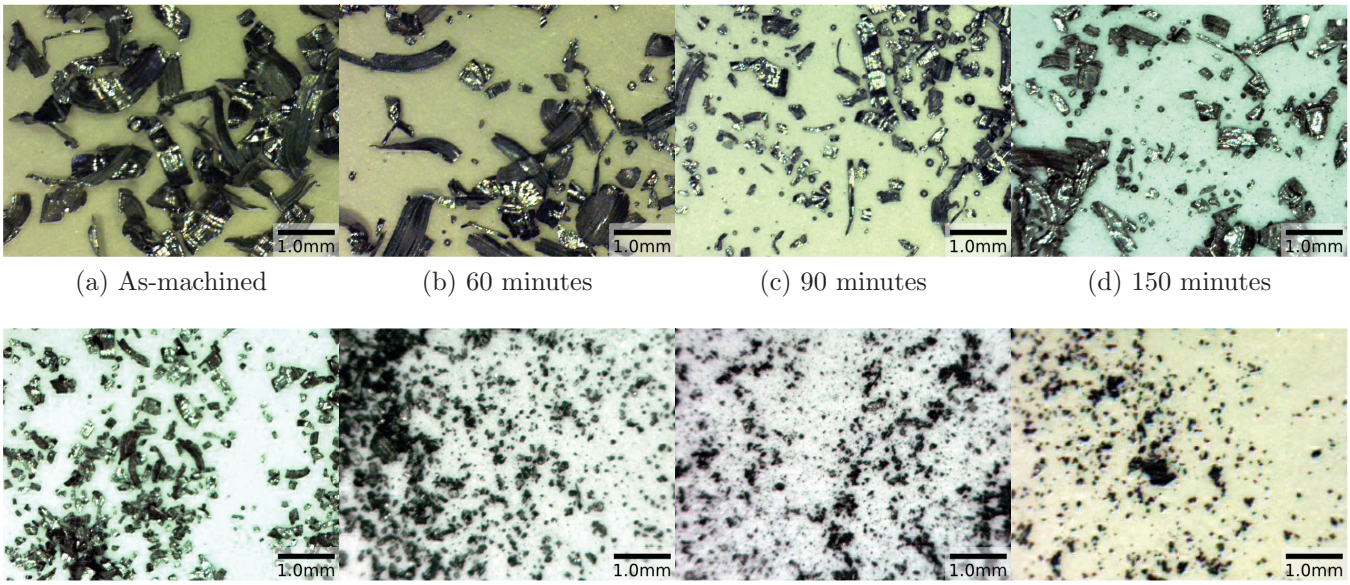


Figure 3: United Nuclear 3lb ball mill used for refining chips into powder.



(a) As-machined (b) 60 minutes (c) 90 minutes (d) 150 minutes

(e) 210 minutes (f) 450 minutes (g) 720 minutes (h) 990 minutes

Figure 4: Ti64 chips ground into powder with a ball mill. The progress of the milling was sampled at the intervals shown.

3.2 Deposition Results

The deposition sample is shown below in figure 5. A difference between the two samples is immediately evident: The deposite made with the recycled powder is dull while the virgin powder deposit is shiny. The sample was sectioned with a wire EDM, mounted in bakelite, polished, and finally etched with Kroll's reagent. As shown in figure 6, this discoloration is not limited to the deposit's surface. The exact nature of the contamination is unknown, but something has clearly been added to the deposited material. The list of suspects include the ceramic polishing media, the ball mill's tumbler, and the AlTiN coating on the mill used to create the chips. An EDS analysis will be used to quantify the contaminants.

4 Directly Feeding Machining Waste

The alternative to refining chips into powders useable by the LAMP system is to enable the system to directly process machining waste. The LAMP team at MS&T is currently working to add multi-format (powder, chips, and wire) material capability to the LAMP system. This capability will allow for choice in source of the feed stock to be based on economics or simple availabilty rather than being limited to expensive powders. The first new component in this initiative, shown in figure 7 is a prototype feeder capable of feeding either powder or chips.

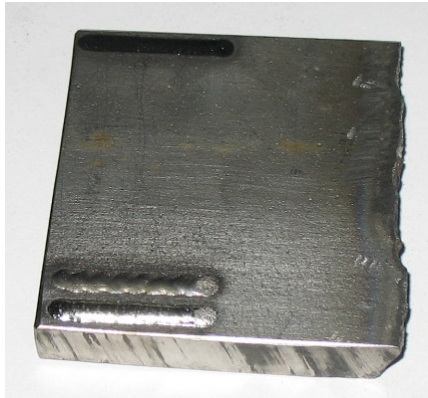
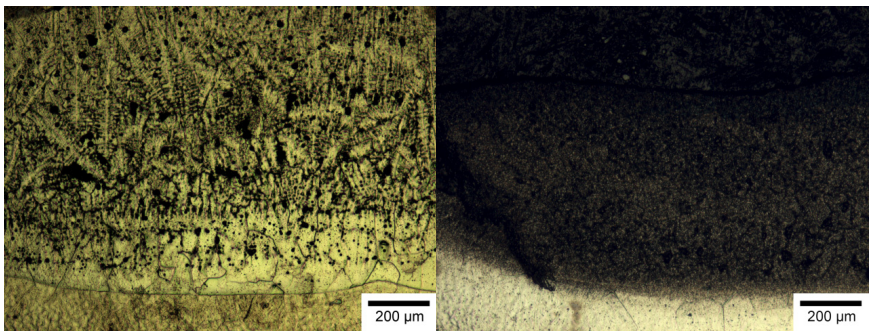


Figure 5: Deposition of the recycled powder and original powder onto a Ti64 plate. Both samples are 4 layers with the following system parameters: 1.0kW laser power, 3 grams/minute powder feed rate, 15 inches/minute travel speed.



(a) Deposition with virgin Ti64 powder.

(b) Deposition with processed machining chips.

Figure 6: Deposition Results

5 Concluding Remarks

Although the ball mill is clearly not the method of choice for refining of chips into powder, the LAMP team at MS&T is making progress toward reuse of its machining waste. An analysis of the contamination in the milled powder sample will determine the next course of action. The chip feeder will be completed in the fall of 2008. These additions to the LAMP facility will enable multi-source material usage, allowing the use of the most economic material for the application.

6 Acknowledgments

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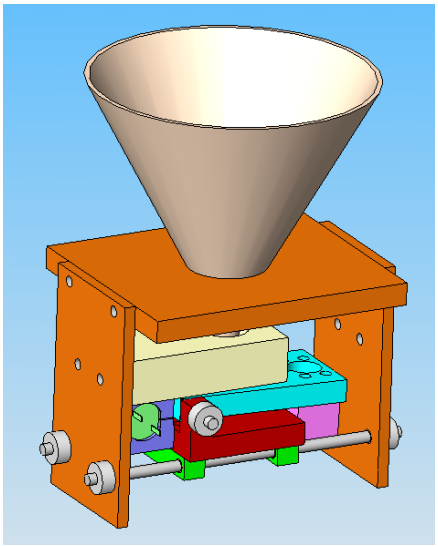

Figure 7: Proposed Design for a chip feeding system.

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