07 Aug 2002

# Laser Aided Part Repair -- A Review

Jinglei Wang

Sashikanth Prakash

Yashodhan Joshi

Frank W. Liou
*Missouri University of Science and Technology*, liou@mst.edu



## Recommended Citation

J. Wang et al., "Laser Aided Part Repair -- A Review," *Proceedings of the 13th Annual Solid Freeform Fabrication Symposium (2002, Austin, TX)*, pp. 57-64, University of Texas at Austin, Aug 2002.

# Laser Aided Part Repair- A Review

Jinglei Wang, Sashikanth Prakash, Yashodhan Joshi and Frank Liou
Department of Mechanical Aerospace & Engineering Mechanics
University of Missouri – Rolla, 1870 Miner Circle, Rolla, MO 65409-1350

**Abstract**

Laser aided part-repair is an emerging trend that has great potential for future industrial applications. Part-repair technologies are currently used in repairing military and civilian equipment. The focus of this paper is to review the current repair processes, which use the laser-aided metal deposition technology. Many metal parts, which are worn by continual use, can be restored to working condition by the deposition of metal with a laser and machining. This not only extends the life of the part, but also, saves on cost. A comparison between various processes, their parameters, efficiency, cost, and etc. are also presented. The process limitations, materials, and areas that are best suited for each process are also discussed.

**Keywords:**
Review, Metal Part Repair, Laser Cladding, Remanufacturing, Laser Aided Deposition, Rapid Prototyping.

## 1. Introduction

Remanufacturing or repair is the process of restoring worn out or damaged products to a workable condition. Any damaged or worn part must be analyzed whether it can be brought back to working order, then it should be made free of rust, corrosion, wear or any surface irregularities. If the parts are found to be beyond repair, they must be discarded or sent for recycling. If not, then the techniques of remanufacturing must be applied, and the part can be restored to working form. After that, a series of reliability tests in the working environment must be simulated for a substantial amount of time to ensure that the part performs as per specifications and its operational range is within the desired limits. All remanufactured components must meet Federal Trade Commission Regulations (FTC). FTC standard ensures the overall quality of the part except for the reliability-testing phase. Some examples of currently remanufactured components are photocopiers, office furniture, auto parts, toner cartridges and even aircraft parts along with various other things [1].

Theoretically, any product that can be manufactured can be remanufactured. The cost of remanufactured goods is cheaper than a new part, and can be remanufactured multiple times, further extending its life. The ideal products for remanufacturing are those that are not likely to suffer from obsolescence, and those whose recoverable value is a high percentage of the price of the new product. Rebuilt engines, for instance, require only fifty percent of the energy and sixty-seven percent of the labor needed to produce a new engine. Hence, remanufacturing should be looked upon as a tool that can save and reuse resources to eventually boost a country's economy [1].

As a sub field in remanufacturing, metal part repair plays an important role in this promising industry. Shown in Table 1 is a simple comparison between various metal part repair processes:

| **Process Type** | **Pre - processing** | **Post - Processing** | **Advantages** | **Disadvantages** |
|---|---|---|---|---|
| Electro Spark Process [2] | Cleaning the work piece for consistency of the part. | A Variety of processes are carried out to ensure Dimensional Stability. | • Prevention of liquid metal erosion and Burr formation.<br>• Improved bonding of Mold Spray. | • No automated applications.<br>• Liquid metal resistant electrodes need to be developed. |
| TGAW, PAW, Brazing & Cladding [3] | • Cleaning the part from dirt, grease, etc.<br>• Preheating the part to alleviate shrinking, cracking, etc. | • Post heating for Stress relief.<br>• Grinding & polishing. | • Intricate repairs can be done.<br>• Produces very high quality results. | • Imperfections in the tooling<br>• Repair shows up as a blemish in the end product.<br>• Limited electrode wear,<br>• Limited intolerance to changes in electrode gap, etc. |
| Metalock Process | Cleaning the part from dirt, grease, etc. | Repaired area is peened flush and finish ground. | • Does not result in any new deformations or stresses.<br>• Effective for Cast iron.<br>• Can be applied on-site. | Cracked pieces are locked together and not fused to a single material. |
| Laser Cladding, LMD, and all other processes using Laser [4][5][6] | Cleaning of the material is required. | • Removal of excess deposit.<br>• Shaping of finished part for visual appeal. | • Can weld huge gaps.<br>• Tolerates procedure variations, resists equipment variations such as end effector wear<br>• Readily accommodates major geometric changes. | • Costs more; hence, it cannot be used for small jobs.<br>• Requires a more complex and advanced control system to get the best results. |
| Robotic Laser Welding Technique [7] | Similar to Laser Cladding | Non – Destructive Examination to check the integrity of the weld. | • High Accuracy, weld integrity and Dimensional stability.<br>• It is portable. | • Costly.<br>• Current applications are limited, like Nuclear Steam Generator repair, etc. |

**Table 1: Comparison between various processes, their basic steps, advantages and disadvantages.**

## 2. Hardware of laser-aided part repair system

### 2.1 Laser aided deposition process

The laser aided deposition process demands repeatability and lower costs. The powder deposition by laser cladding is mainly used for part repair due to a localized heat affected zone, to improve surface qualities and has a good control over the desired set of parameters. It has a vast scope in dies and molds to high replacement cost components that need to be salvaged. The process involves a combination of cladding and machining steps. For successful cladding of material, various cladding parameters need to be studied and maintained at optimum value by real time control.

A laser metal deposition system involves the supply of metallic materials into a laser generated heat spot where the material melts and forms a melt pool, which quickly solidifies into metal layers. As the metal powder passes through the laser beam, it is melted and deposited in the melt pool created by the laser beam on the metal substrate. The metal powder forms a metallurgical bond with the substrate to give it good material properties.

The basic metal cladding system consists of a positioning and clamping system, an energy delivery system and a powder delivery system with auxiliary systems such as a cooling system, a control system and sensors for parameter control, a machining system, a size and shape detection system, a scanning system, and an automatic NC code generation system. The CNC table can have a three or higher axes capability for successful cladding of complex parts with overhanging features and hollow features. The control system includes sensors, CCD cameras and a computer workstation.

### 2.2 Laser-aided Part Repair Systems

The part repair systems can be classified as an onsite or offsite repair system. The onsite repair systems are used for dedicated applications for the repair of high value, large replacement cost components. The offsite repair systems are general-purpose repair systems for repair of various small components.

Complete description of a dedicated onsite part repair system can be conducted by describing the following facets: laser, type of repair, gas, powder used, motion control device, system arrangement and special devices, process parameters, etc. Table 2 shows several current laser-aided repair systems.

| | Steam Generator Repair[7] | Navy Aluminum Components repair[8] | Die restoration [18] | Blade and Blisk repair[16][17] |
|---|---|---|---|---|
| *Type of repair* | repairing corroded steam generator tubes by sleeve welding method and used at nuclear | High value aluminum components that are subject to wear and corrosion | Plastic injection molds and die cast tooling | Gas turbine blades |

| | | | | |
|---|---|---|---|---|
| | power plant in Belgium | | | |
| *Process* | Laser welding | Laser cladding | Closed-loop DMD | Laser powder welding |
| *Laser* | 1000W CO2 laser | 3.0 KW YAG laser | CO2 laser | |
| *Material* | Not available | Aluminum alloy, such as 7075/7175,6061 | Metal powder: Tool steel, copper alloys or OFHC pure copper | Inconel 738 |
| *Gas* | Helium was used for inert atmosphere | Argon or helium | Argon or ArHe | Argon |
| *Motion Control* | Operated through an umbilical cord from a trailer by an operator using commands to a computer, which calculates the angles and position of each axis of the arm. | A six axis assembly robot which has special end-of-arm robotic tooling containing the laser lens, powder tube, inert gas tube and fume elimination system as a single unit. | Not available | Not available |
| *System Arrangement and special devices* | A 6- axis robotic arm ROSA is used along with cameras for position detection and non-destructive examination sensors | A special fixture table was designed for fixing and rotating shells | Not available | 3D digitizing system is used to create 3D model of the components |

**Table 2: Comparison of various dedicated onsite part repair systems.**

For the laser delivery mode, the steam generator repair system has a unique beam delivery system that transmits the laser beam between the transmitters from the laser head to the end effector without a mechanical connection, using motor driven mirrors and a computer controlled system, with a He-Ne alignment laser and a short pulse laser. [7] While the Navy aluminum component repair system has a fiber optic delivery capability and a time-share system to independently supply laser energy to four processing rooms. A light tight enclosed processing room of a class four laser rating is used with an attached control room[8] .

## 3. Software of laser aided part repair system

A laser aided repair system involves extensive hardware, including a 3D digitizing system, CNC machines, a laser-aided metal welding/depositing system, etc. However, in order to develop an efficient repair system, hardware alone is not sufficient. Too many manual operations will reduce the final part's quality and make the process time unacceptably long. Hence, software is required to guarantee effective communication among the different components in the whole system. The main objective of the software is to get a laser path and tool path from the digitized data of the damaged part.

In a laser aided repair process, the damaged section will usually be cleaned and digitized. Then, the machining tool path and the laser path need to be calculated by special software. After this preparation, the "milling-depositing-measuring" cycle will be repeated until the product meets the geometry and mechanical constraints. The process is shown in the Figure 1.

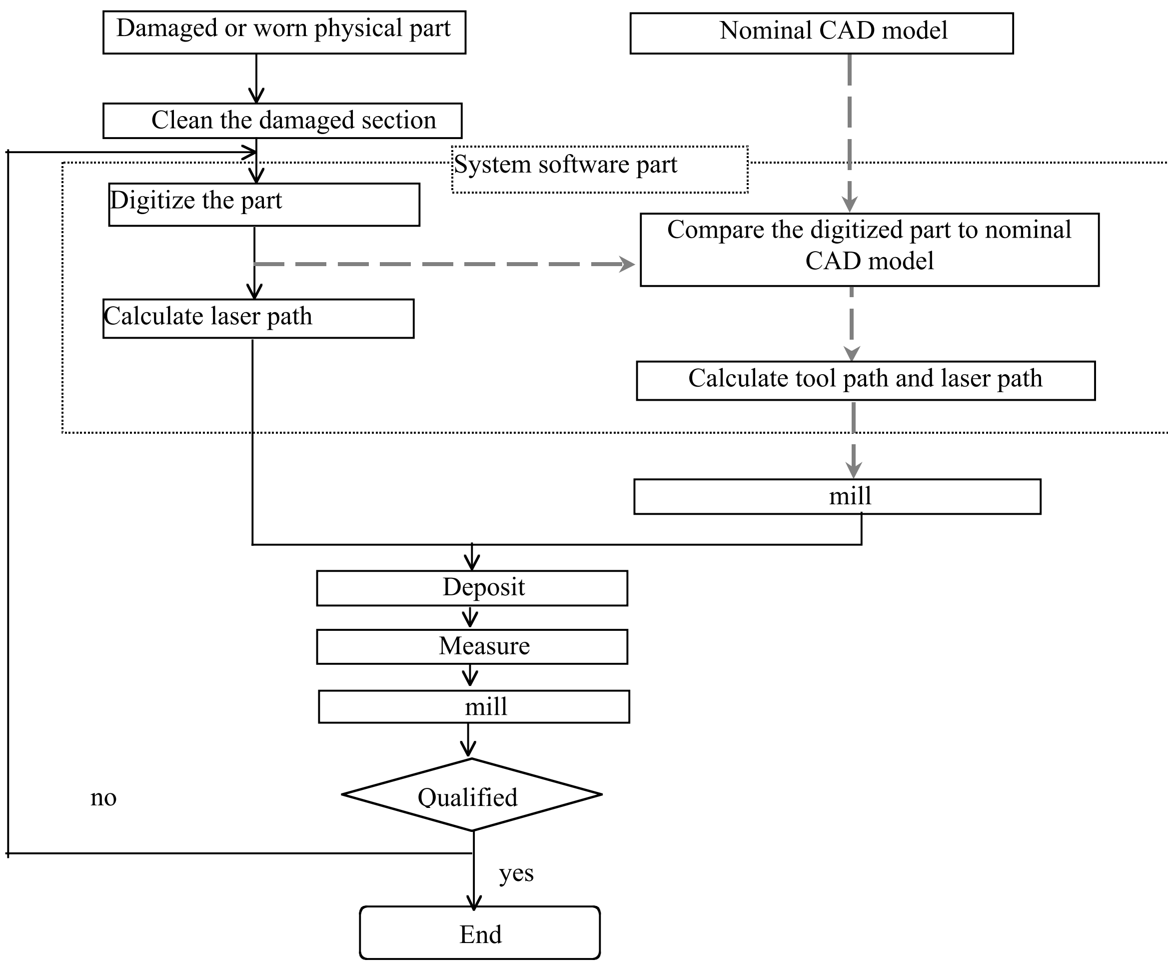


**Figure 1. The process chain of a laser-aided part repair system**

When the part's shape is simple, original nominal CAD models are not always necessary. The calculation of the laser path only depends on the digitized data. In some cases, such as a washed-out turbine blade of an industrial gas turbine fuelled with crude oil [18], the remaining wall is not thick enough to be pre-machined. Therefore, the milling step before the deposition can be ignored.

In every step of the repair process, a special format of data is used. The data flow in such a repair system is shown in Figure 2:

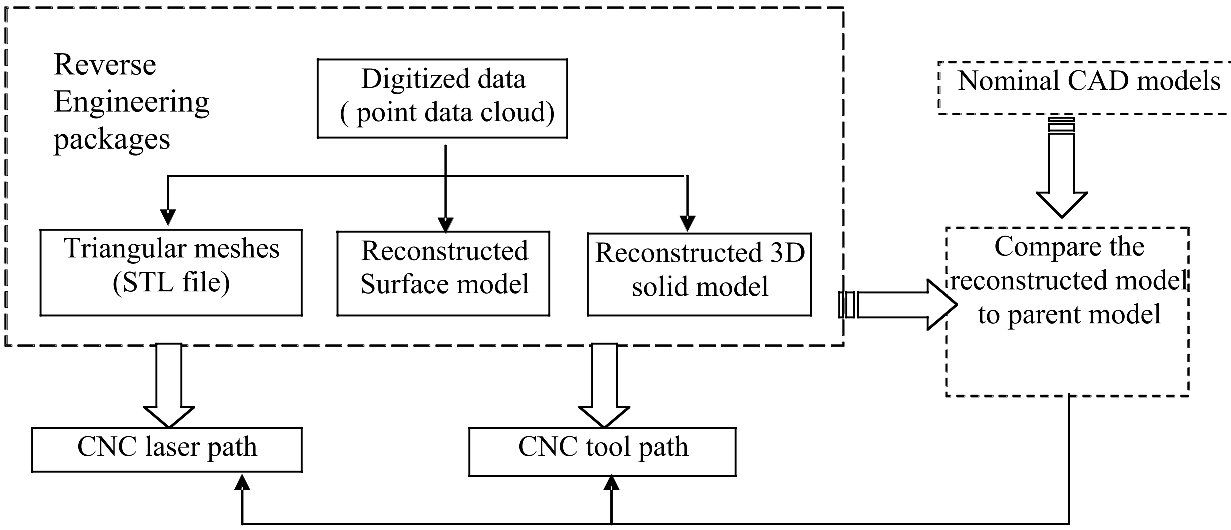


**Figure 2. the data flow in a laser-aided part repair process**

The inputs are the digitized data and the nominal CAD models. Outputs are the laser and CNC tool paths. In the reverse engineering process, software packages transfer digitized data into triangular meshes, reconstructed surface models, or reconstructed 3D solid models. The laser and CNC tool paths can be generated directly from the digitized data [21-23]. However in the case of repairing a part, the part is not rebuilt from the very beginning. Usually, the nominal CAD model of the parent part is compared to the actual digitized model so that the minimum steps of depositing and machining can be calculated. Current reverse engineering software still cannot solve this problem satisfactorily. The comparison algorithm and method are still in the research stage and is often application specific.

Claus Bremer [19] used a best-bit method to match the surface representation of the nominal geometry and the actual geometry corresponding to scanned points. Then, based on the resulting mathematical description of the actual geometry – by an adaptive manufacturing method – the NC paths can be generated.

Monica Bordegoni and Stefano Filippi [20] used a special software package, Cimatron, to compare the reconstructed models and the nominal models. With this software, the digitized point cloud can be processed to calculate the actual surface model. When the parent model and actual model are combined, the difference between these two models can be described.

In summary, the software for a laser-aided repair system is an integration of a reverse engineering package, a laser and CNC tool path generation program, and comparison packages. To compensate for the variation among the damaged parts, adaptive manufacturing technologies are applied and the software packages made tend to be application specific.

## 4. Part Qualification

Part Qualification is an important phase where various tests are conducted on an ideal part and various parameters are obtained from it. These values serve as mandatory benchmarks for qualification of repaired parts [6] [8].

- Before repairing a damaged part, check the degree of damage and the degree of repair required for its restoration. If the repair looks infeasible, then abort the process and send the part to be recycled.
- If the part clears the previous step, then check the physical integrity of the part by subjecting it to a series of testing procedures. If the part passes this phase, then begin the restoration process.
- After bringing the part to the required dimensional specifications and tolerances, by the various processes of repair, subject the part to further testing by simulating a working environment for a considerable time to ensure smooth functioning of the part. The working conditions must be more severe than the actual conditions to ensure that the result is always reliable. If the part meets the criteria, then clear the part for reuse. If not, then reject the part.

## 5. Conclusion

Laser-aided metal part repair is a promising technology in the remanufacturing industry. It involves extensive advanced technologies, such as lasers, 3D digitizing systems, CNC systems, laser-aided rapid prototyping systems, reverse engineering software, etc. Compared to the conventional repair methods, it has the following advantages:

- Very small heat-affected zone, which results in tiny deformation and stress.
- Can be applied to virtually all metal materials.
- Operation time is significantly shortened compared to arc welding.
- Final product has high dimensional accuracy and integrity.

Currently, this process has been successfully applied to repair blades and blisks, torpedo shells, tools, dies, nuclear sleeves and etc. With the development of the related technologies, the laser-aided part repair process will be used in more fields.

## 6. Acknowledgments

This research was supported by the National Science Foundation Grant Number DMI-9871185, Missouri Research Board, and a grant from the Missouri Department of Economic Development through the MRTC grant. Their support is appreciated.

## 7. References

[1] Remanufacturing Vision Statement. Facilitated by the U.S. Department of Energy, Office of Industrial Technologies.
[2] Shoju Aoshima, Electro-Spark Process for Repair and Maintenance of Die-Casting Dies, TechnoCoat International, Japan.

[3] Mike Sammons, Product Manager, Miller Electric Mfg. Co. Appleton, Washington, Learning the art of Tool and Die Welding Repair.
[4] Sjef Mattheij, Technical Director, Elbar BV, Sulzer Turbomachinery Services, Spikweien, Lomm, Netherlands, Turbine Repairs now possible with Laser Powder Build-up Welding Technique.
[5] J. Laeng, J. G. Stewart & F. W. Liou, Laser Metal Forming processes for Rapid Prototyping – a review.
[6] P.M. Brown, G. Shannon, W. Deans & J. Bird. Laser Weld repair of Fatigue cracks in Ship Steels.
[7] Andrew Wowczuk, Richard Miller,Geald Bruck," Robotic laser welding system improves steam generator repair" , Power Engineering, Jan. 1990.
[8] James De Camp, Pat Bergan, 21-24 August 2000, Implementation of Laser Repair Process for Navy Aluminum Components.
[9] Jonathan C. Owen, Peter-Pike J. Sloan, and William B. Thompson, Interactive Feature-Based Reverse Engineering of Mechanical Parts, IEEE Transactions on Robotics and Automation, 1999
[10] Pierrette Gorman, John E Smugeresky and P.M.Kiecher, Enhanced process window evaluation for laser engineered powder metal deposition, Metal powder deposition for RP conference proceedings 2002.
[11] Karen M.B.Taminger, Robert A. Hafley and Dennis L. Dicus, SFF: An enabling technology for future space missions, Metal powder deposition for RP conference proceedings 2002.
[12] J.L Koch and J.M Mazumder, "Rapid Prototyping by Laser Cladding",
[13] M.A. McLean, G.J Shannon and W.M. Steen, " Laser generating metallic components"
[14] M.Qian, L.C. Lim, Z.D. Chen and W.L. Chen, "Parametric studies of laser cladding processes"
, Elsevier Journal of Material Processing Technology.
[15] J.Y. Jeng, S.C. Peng and C.J. Chou, "Metal rapid prototype fabrication using selective laser cladding technology" , the international journal of advanced manufacturing technology-2000,
[16]Stefan Krause, An Advanced Repair Technique: Laser Powder Build-up Welding, Sulzer Technical Review, 4/2001, P4-6.
[17]B. Stimper, Munich, Using Laser Powder cladding to Build Up Worn Compressor Blade Tips.
[18] C. Bremer, Adaptive Welding Strategies for Repair and Overhaul of Turbine Blades and Blisks, 3rd International Conf. On Laser Assisted Net Shape Engineering, Erlangen, Germany, 2001
[19] Claus Bremer, Adaptive Strategies for Manufacturing and Repair of Blades and Blisks, Proceedings of ASME Turbo Expo 2000: 45th ASME International Gas Turbine & Aeroengine Technical Congress, May 8-11, 2000, Munich
[20] Monica Bordegoni, Stefano Filippi, Reverse Engineering for Molding
[21] W. Thomas Welsh, Introduction to CAD-Driven Reverse Engineering, Designing With Reverse Engineering Society of Manufacturing Engineers IMTS Conference, September 7, 2000.
[22] William B. Thompson, H. James de St. Germain, Thomas C. Henderson and Jonathan C. Owen, Constructing High-Precision Geometric Models from Sensed Position Data
[23] C. Bremer, Ralf Drewing, 3D Digitizing and Data Processing for Efficient Reverse Engineering and Adaptive Manufacturing