Computer Aided Contour Profiling of High Strength Deposits

Sriram Praneeth Isanaka[1], Amar Bala Sridhar[2], Frank Liou[1], Joseph W. Newkirk[3]

[1]Department of Mechanical & Aerospace Engineering, Missouri University of Science and Technology, 400 W. 13th St., Rolla, MO 65409, USA

[2]Department of Manufacturing Engineering, Missouri University of Science and Technology, 400 W. 13th St., Rolla, MO 65409, USA

[3]Department of Materials Science & Engineering, Missouri University of Science and Technology,
223 McNutt Hall, Rolla, MO 65409- 0330, USA

Keywords: Metal deposition, deposit contouring, coordinate measurement, 3D scanning, curve fitting, contact angle, ripple effect.

Reviewed, accepted September 23, 2010

ABSTRACT

Additive manufacturing processes suffer from the effect of ripples, edge rounding and surface variations. To reduce their effect, ideal process parameters for the laser deposition process were investigated. Also, a new method was identified to analyze deposits by accurately plotting their contours. This was achieved through point cloud data of the deposits generated using coordinate measurement and 3D scanning. Curve fitting was performed on the data in Matlab to generate the contours of the deposit. The intercept values, heights, and contact angle of the curves give an indication of the uniformity of deposits and aid in reducing defects.

INTRODUCTION

The Laser aided material deposition at Missouri university of Science and Technology consists of two major subsystems: Laser deposition system (Rofin Sinar 025) and CNC mill (Fadal VMC-3016L). The subsystems share common x-y translator and rotary-tilting table; but have independent z-axis movements and the entire system is capable of 5-axis motion. The laser deposition system includes a laser and a powder delivery system. The principle of laser deposition is as shown in figure 1. The Rofin Sinar laser with energy up to 1KW is used to fuse powder on to the underlying surface (substrate). The laser delivers heat while the powder delivery system feeds powder at a uniform rate into the melt pool created by the laser. The 5-axis CNC machining makes it possible to directly produce fully-functional parts with a quality surface finish. Its many advantages include: Eliminating the need for support material, crafting complex contours easily, reducing processing time and eliminating profile constraints which are typical with 3-axis milling. Figure 2 shows the Laser Aided Manufacturing Process (LAMP) system during deposition. The Hardness values obtained by the LAMP system are comparable to other manufacturing processes. The major applications of the process include coatings, functionally graded materials, and repair and maintenance of designs prone to crack failure.

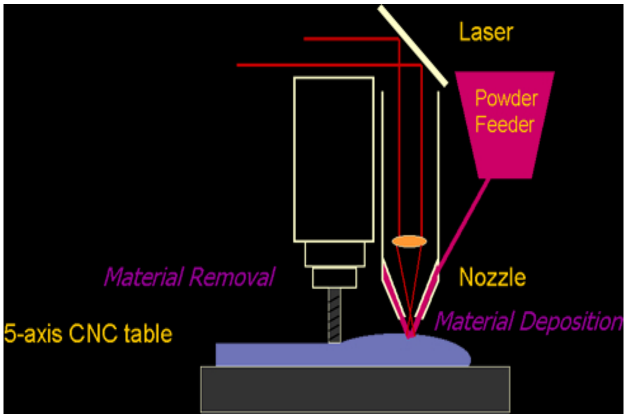


Figure 1: Principle of LAMP

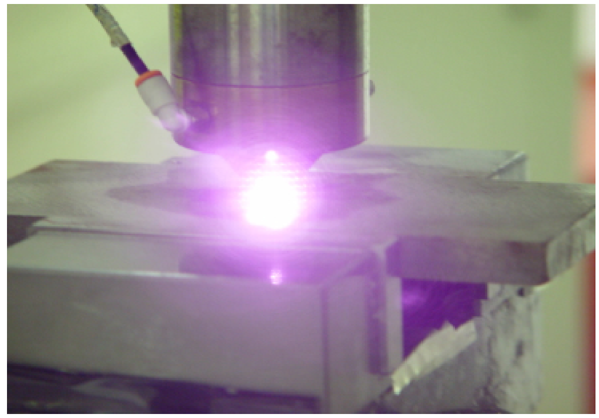


Figure 2: 5 – axis laser deposition system

PAST WORK

Graphic Representation of results is essential to understand the numerical behavior of a mathematical model solving a physical problem. The representation substitutes analysis of a mess of large data by a simple visual inspection. Contour plotting of data is one step towards such representation. Contour plots show the same value of a physical parameter in a geometric domain. It is an indispensable method for graphical representation of results. Contour line plots offer visual information that is not obvious from looking at voluminous numerical data.

For contour profiling data obtained from CMM or 3d scanning was used. The use of 3d scanning ranges across many fields. It has been used in geometric morphometric analysis of craniofacial shape [1], laser profilometer [2], Feature extraction of concrete tunnel liner [3] and structural modeling [4], documenting data from 3d body scanning [5], art [6] and sculptured surface digitization [7]. It is useful because the laser scanning data simultaneously provides geometric and radiometric information of objects. The geometric data, the x, y and z coordinates of the objects, are recorded by the principle of time-of-flight, which calculates the distance between the laser scanner and the target with the traveling time of the laser or via the phase difference of the laser rays. Through accurate geometric information provided by laser data and high sampling density, precise information regarding the three-dimensional (3D) features of structures can be provided.

CMM has remarkably improved the ratio of cost and performance. It has achieved wide popularity as a flexible solution to a myriad of measuring needs. CMM captures the coordinates of points on the work piece surface. It finds its usage more in the post production or quality stage [8]. Our use of the CMM and 3 D scanning is more in the design & development stage. We have used measurement tool in the initial stages of our design. This is used to give greater insight into the process involved and will enable in taking decisions for either rapid prototyping or manufacturing.

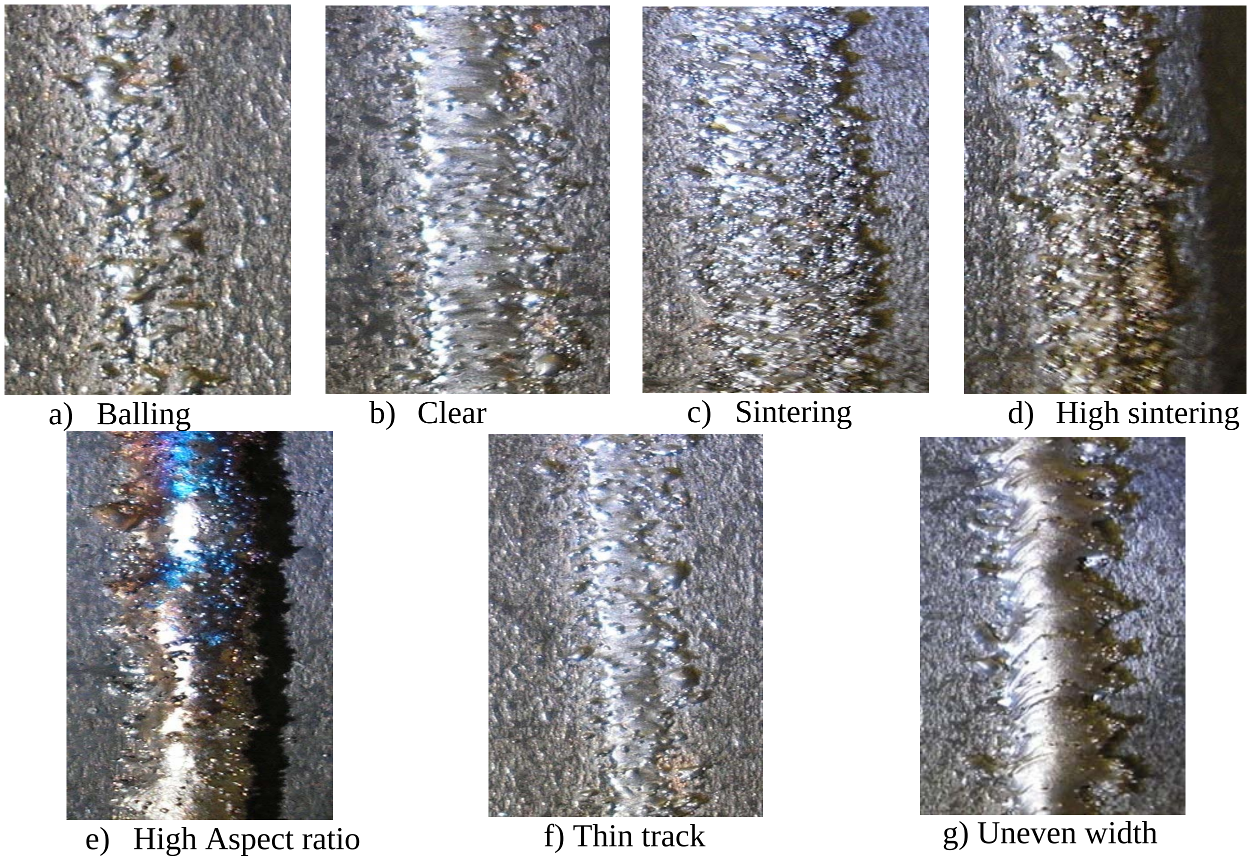


Figure 3: Classification of LAMP powder deposits by visual inspection

The major process parameters that affect the finish of the deposits made by LAMP are the powder used, powder feed rate, table velocity and laser power. Every powder including stainless steel & titanium to alloys such as tribaloys and tungsten carbide matrices possess diverse physical properties. Therefore the ideal deposition values for the process parameters vary with differing materials. In the past, ideal deposition parameters were identified by visual inspection of the deposits [9]. The classification of powder deposits by visual means in shown in figure 3. High resolution digital images of the deposits are taken and analyzed visually to classify them into clear, sintered, uneven width or balled tracks etc. The use of this method to identify ideal parameters is tedious and time consuming. It is also not very accurate as it involves the viewer's intuition and is mostly based on past experience.

To address these difficulties we identified the need for a more quantifiable method. The major priority of this new method was to improve accuracy during deposit analysis without human error. The comprehensive data obtained from this method is to be used in process planning software being developed at Missouri S & T for the LAMP process.

PROCEDURE

After identifying the need for a novel method, significant brainstorming led to the proposal of creating 3-dimensional surface maps of our deposits. This was accomplished by generating point cloud data of the outer surfaces of the deposit and the substrate. The data was then post processed using matlab to provide meaningful results. Error identification and verification then followed and applied to the point cloud data to obtain very accurate 3-D surface plots of the deposits. These plots led to the identification of the variations in deposit heights, intercept lengths and edge rounding phenomenon with greater accuracy. A schematic of the procedure is shown in figure 4. The procedure can be broadly classified into 4 stages: data acquisition, post processing of data, accuracy verification, and output.

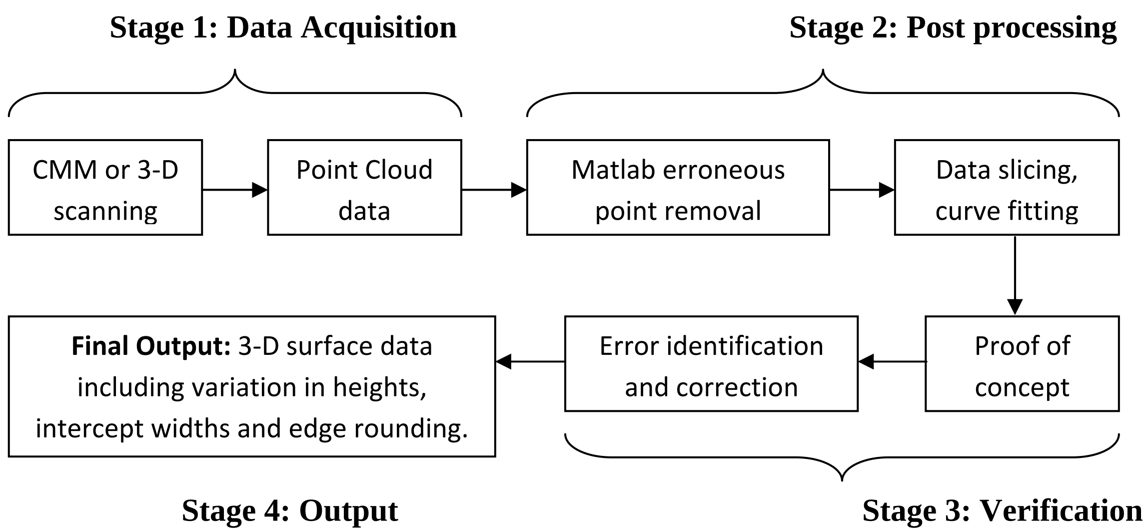
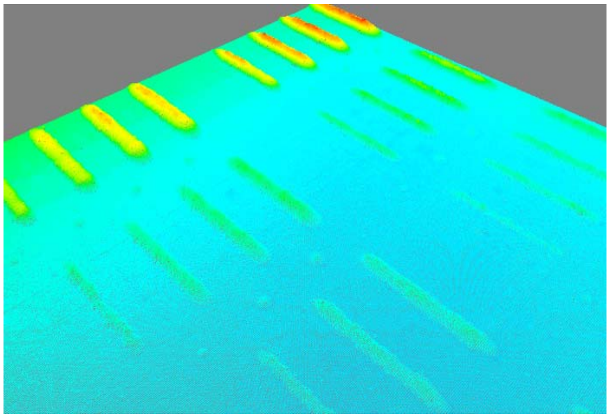


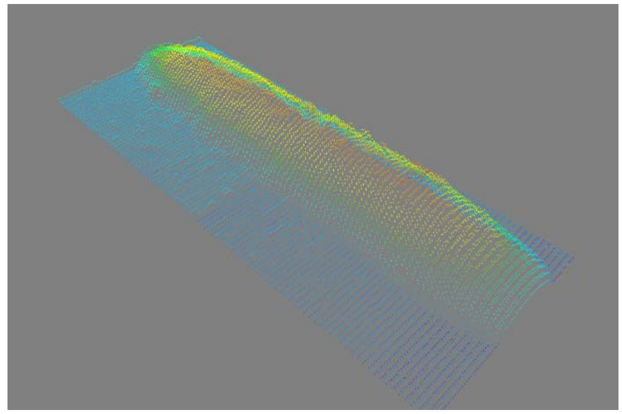
Figure 4: Schematic for obtaining 3-D surface data

Stage 1: Data Acquisition

In an effort to obtain accurate 3-D surface plots, point cloud data of the surface was gathered by using Co-ordinate Measurement Machine (CMM) and 3-D scanning. Illustrations of the point cloud data obtained by the two methods are shown in figures 5 and 6. The CMM used for obtaining the above data was developed in-house, for use in this project. It has a resolution of 0.0025 inches and generates approximately 2-3 million points per scan. Very little data losses are found while using this process and it provides a complete scan result. The disadvantage with this process is that it is time consuming. It takes approximately 48 hours to obtain 2 – 3 million points (single run). It provides point cloud data in .vtk formats that can be imported into matlab for post processing.



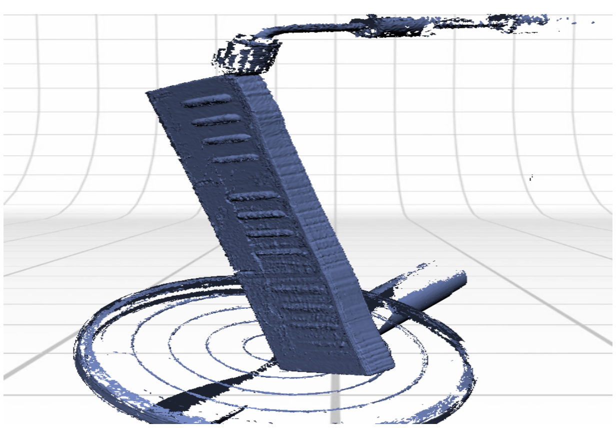
a)



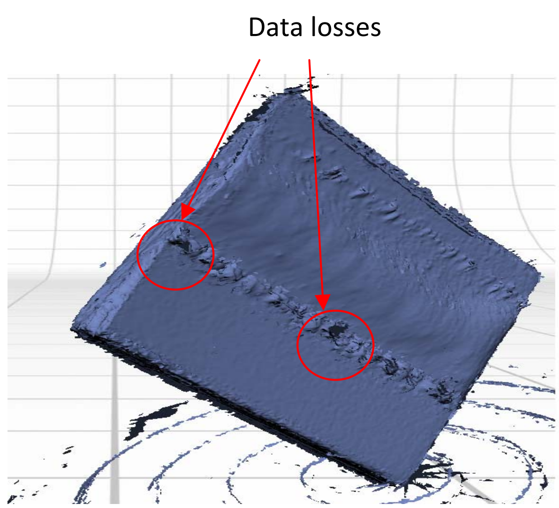
b)

Figure 5 (a & b): Visualizations of CMM point cloud data in MAYA.

The other method used for data acquisition is 3-D scanning. For the experiments a NEXTENGINE 3-D desktop scanner was employed. It has a much higher resolution than that of the CMM. This method produces approximately 10 million points per scan which is both an advantage and a disadvantage. Although it ensures larger and better data set, the large numbers of points pose considerable problems while post processing. The advantage of this process is the minimal time required for data acquisition. A complete scan of 10 million points can be made in less than 90 minutes making this process extremely fast and efficient. The major problem with this method is loss of data owing to line of sight issues as exhibited by most 3-D scanners. The scanner acquires only data that is unobstructed in its view. This can be clearly seen in figure 6 (b). This method provides data in .xyz format which can also be imported into matlab for post processing.



a)

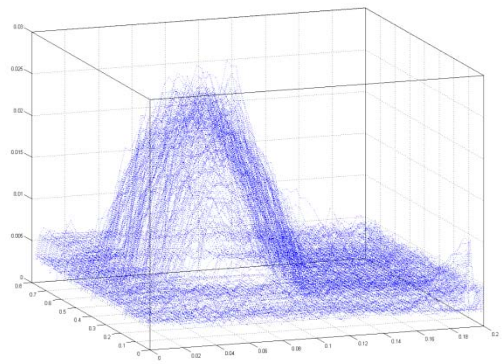


b)

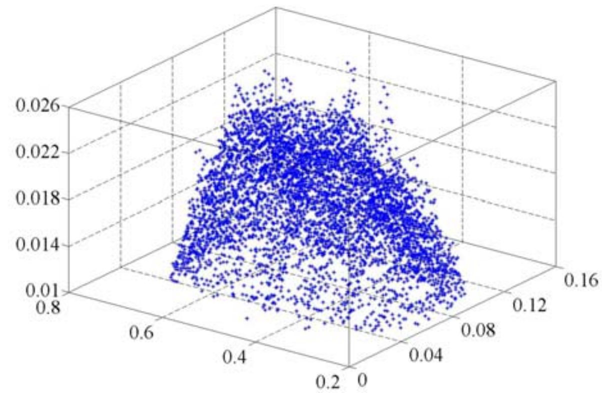
Figure 6 (a & b): Visualizations of 3D scan data obtained using NextEngine scanner.

Both the methods are ideal for our process as they generate the required data. Alternating between the two based on the need for speed and accuracy was best option that was proposed. The point cloud data obtained by this method was then imported and post processed in matlab.

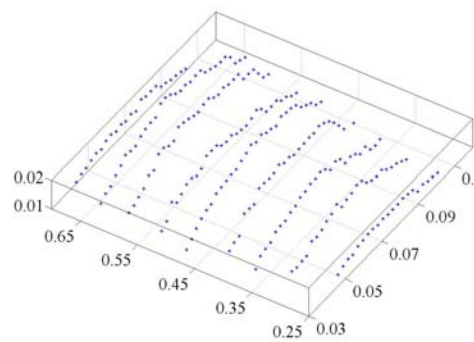
Stage 2: Post processing



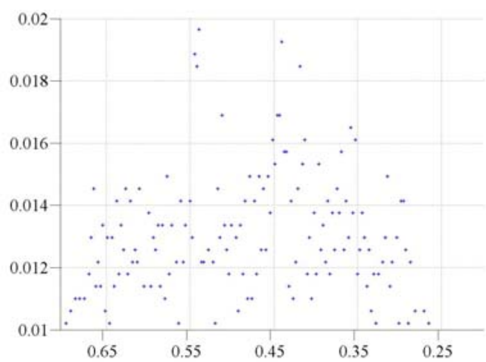
a) Point cloud data plotted in matlab



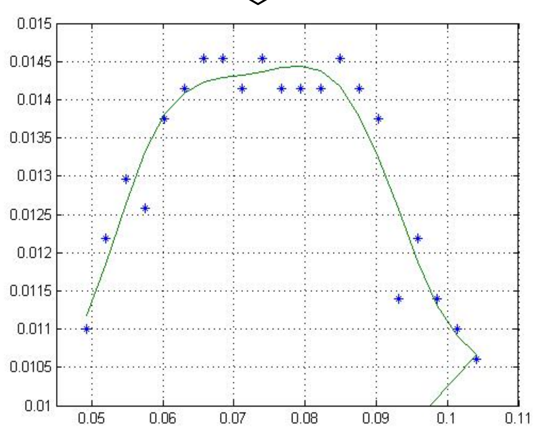
b) Point cloud data after junk data points removed



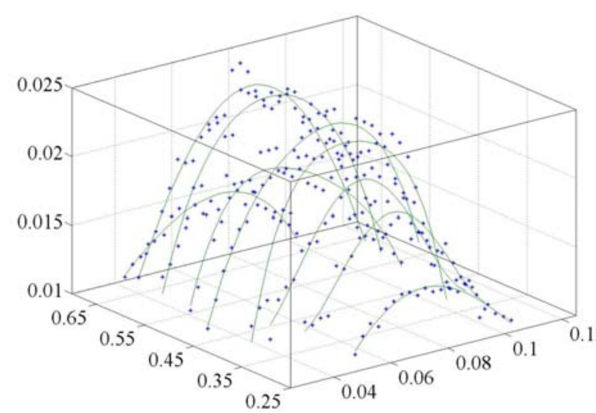
c) Data split into individual slices



d) Point data from single slice



e) Single slice data with curve fit



f) Rough contour profile of the deposit.

Figure 7 (a, b, c, d, e, f): Procedure for post processing of data (All axes represent dimensional values in x, y & z directions. All dimensions are in inches)

During post processing, the point cloud data with 3 millions points is broken down into manageable sizes of around 50,000 points. Such a broken down file is shown in figure 7 (a). It can be seen that the point cloud contains points which show the surface of the substrate. All points that do not represent the actual deposit in question are considered junk and are filtered out of the file using matlab programming. Such a file that includes only the deposit point cloud is shown in figure 7 (b).

During the course of the analysis it was noticed that removing these junk data bring down the number of points by about 50 – 60 %. The data at this juncture contained approximately 20,000 points. Although the clutter had been significantly reduced from the data the number of points, were still too great to draw meaningful conclusions. Therefore we came up with the idea of slicing the data to further reduce the number of points. The slices were picked at regular intervals and can be used to predict the variations of height and the trend of the data without the need for using the entire data set. Figure 7 (c) shows a data set with a few slices. These slices were then fit with curves to represent the outer shape as shown in figure 7 (d) and 7 (e). A large number of these slices together can accurately represent the outer surface of the entire deposit as shown in figure 7 (f).

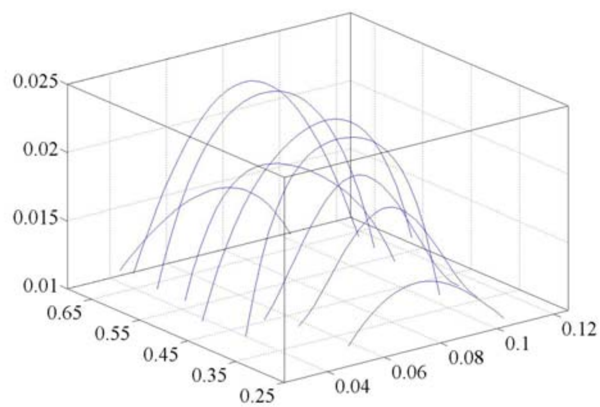


Figure 8: Output after post processing the data. (Axes represent dimensional values in x, y & z directions. All dimensions are in inches)

The greater the number of slices employed the more accurately they will portray the varying trend in the data. Employing slice data helps identify heights and intercepts accurately while also ensuring a small data set to work with. The output obtained after the post processing is shown in figure 8.

Stage 3: Verification

The point cloud data obtained by this method contains numerical values up to the eighth decimal point. Although the data seems comprehensive and can predict trends very well, the validity of the data obtained was yet to be verified. The next task was to ascertain that the data obtained matched the cross-sectional profiles of the deposits made.

During our initial experiments forty eight deposits of tribaloy- 400 were made on 4340 steel by varying the powder feed rate, table velocity and laser power. The deposits are shown in figure 9. To aid in the verification, the deposits were coated with J B weld and the cut to photograph the cross-sections of the deposits. The cut cross-section would now represent a single slice of data obtained from matlab. The photograph of the cross-section and the slice data image from matlab were then superimposed to check the validity of the data. Such an image is shown in figure 10.

Figure 9: Experimental deposits of tribaloy - 400

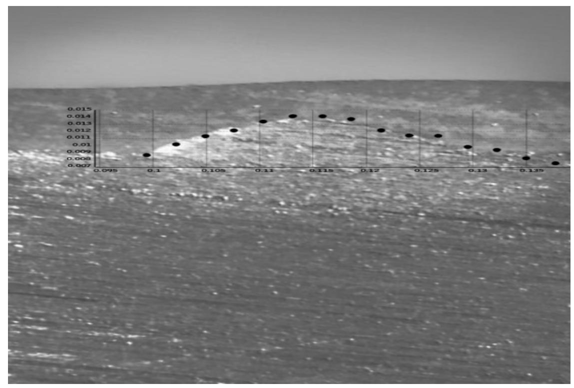


Figure 10: Superimposed images for verification

It can be seen from figure 10 that data obtained from matlab and the photographs are a near perfect match. This proved that data obtained was valid and any error in the data was beyond the 4^{th} decimal point which was to be negated by fitting curves to the data. Based on the above results a number of intuitively chosen curves were fitted to the data set. The curves primarily investigated were polynomial curves of multiple orders and moving average curves from 2 – 25 points as shown in figures 11 and 12. Owing to the simple shape of the deposit cross-sections there was no need to investigate more complex shapes such as splines or Bezier curves.

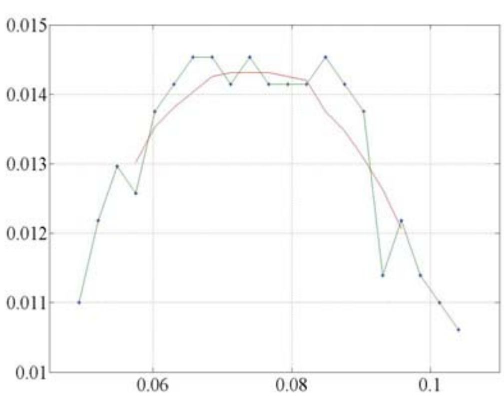


Figure 11: Moving average with 6 points

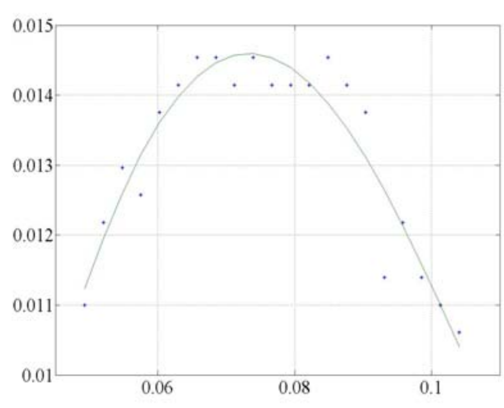


Figure 12: Polynomial curve of order 2

(Axes represent dimensional values in x & z directions. All dimensions are in inches)

Cross-sections of deposits can be made in both x and y direction. After our analysis it was found that polynomial surfaces of lower order fit the cross-sections made along the x-axis well enough to depict the outer surface of the deposits. For the cross-sections of deposits made along the y – axis moving average curves with around 25 points and polynomial curves of higher order were noticed to best depict the actual deposit as shown in figures 13 and 14.

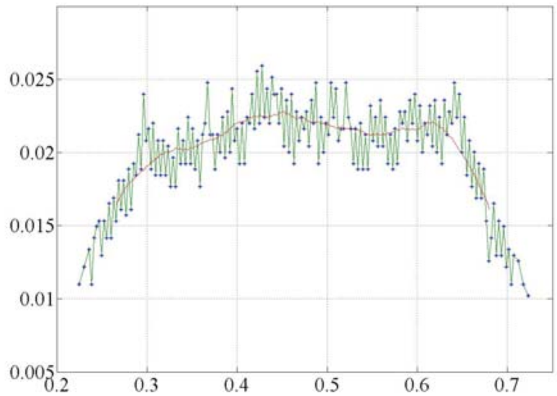


Figure 13: Moving average with 25 points along y-axis

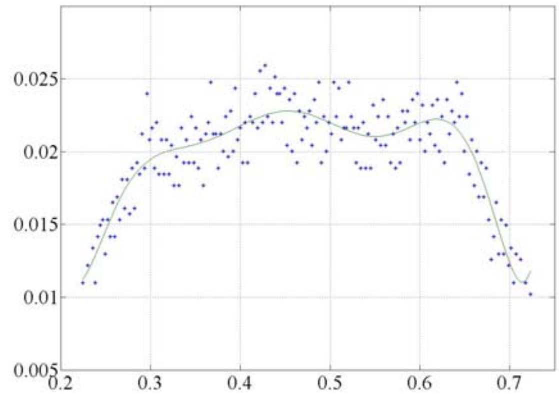


Figure 14: Polynomial curve of order 5 along the y - axis

(Axes represent dimensional values in y & z directions. All dimensions are in inches)

RESULTS AND DISCUSSION

From the final point data and curves, intercept widths, varying height values and edge rounding effects were obtained. Figure 15 show the intercept points of multiple slices with connecting lines which indicate the width.

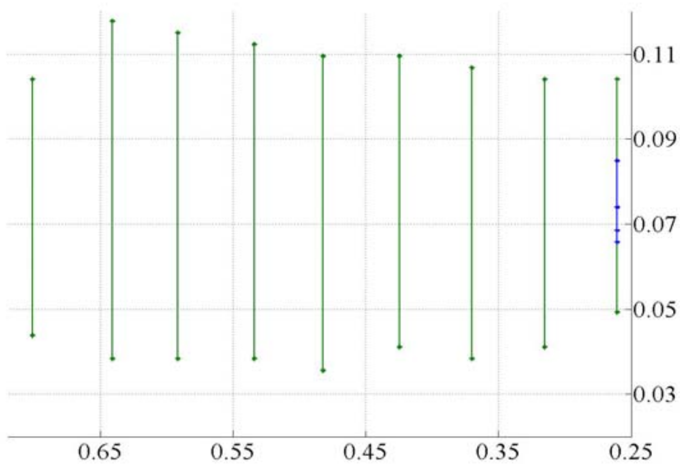


Figure 15: Intercept points and widths as seen from the top of the deposit. (Axes represent dimensional values in x & y directions. All dimensions are in inches)

It can be seen from the figure that the intercept widths vary with deposition. All the 48 deposits made indicated variations to a certain extent. The trend is that at the start and end of the deposition the intercept width is smallest. During the course of the deposition the variations persists, but to a lesser degree than at the start and stop. This a common problem in all powder additive manufacturing processes where controlling the powder particle’s position to accuracy greater than 0.001 inches is still difficult. The method proposed can identify these minute variations and help with process planning. With the above data all problems related to geometric difficulties and post process material removal can be significantly reduced.

The method also very accurately plots the height profile of the deposits. Using this, the extent of edge rounding effect due the varying laser heat was analyzed. The edge effect is predominant during start and stops of the deposition and was initially assumed to be equal in size to the width of the laser beam. The new measurement method though indicates that it is 1.5 times the width of the laser beam. Also the ripple effect or waviness in the deposit due the variations in the process parameters was also gathered. Variations in height due to sintering and powder flow velocity have been studied in depth with a much more quantifiable method to generate optimum parameter values. The height variances during deposition are shown in figure 16.

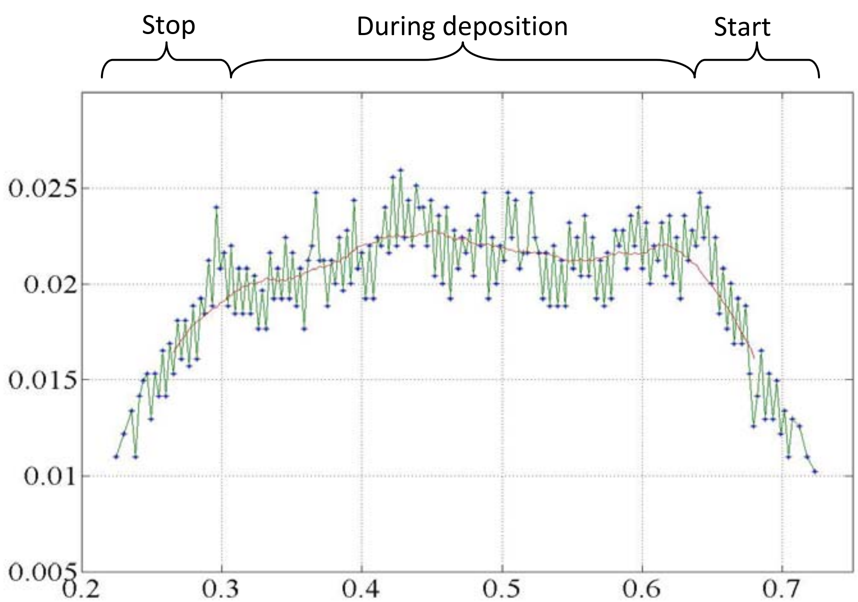


Figure 16: Varying height profile of the deposit with a moving average trend. (Axes represent dimensional values in y & z directions. All dimensions are in inches)

Upon analyzing all forty eight of the tribaloy – 400 deposits using contour profiling we have found that tribaloy – 400 is best deposited using the values shown in table 1. Very fine deposits of tribaloy – 400 were made using the values in the table. An example is shown in figure 17.

Table 1: Ideal parameter values for tribaloy – 400 depositions obtained using computer aided contour profiling

S. No	Parameter	Value
1	Laser Power	800 W
2	Table Velocity	14 inches/min
3	Powder feed rate	6 inches/min

Figure 17: Sample deposit made using ideal process parameters

CONCLUSIONS

The need for a new measurement and analysis method was indentified and computer aided contour profiling proposed and implemented. Point cloud data from both CMM and 3-D scanning was obtained and post processed to get the required results. Heights profiles, edge and ripple effects and varying intercepts widths have been analyzed for tribaloy – 400 deposits. This has led to the prediction of ideal process parameter values and a change in outlook over the edge effect occurring in the LAMP process. When this data is used in combination with a process planning software it can help in

- Predicting ideal material and particle sizes.
- Predicting geometric complications.
- Calculating tolerances.
- Reducing post process milling.
- Predicting ideal LAMP machine parameter values.

This major advantage of this method is its ability to be applied in any application. Rather than using 3-D scanning and CMM as art or quality control tools, we can now use them to obtain very accurate data and analyze. The equipment cost involved in this process is also minimal. The flexibility and accuracy of this method can be employed to good effect in anatomical studies, biological sample measurements, conceptual designs of next generation aircrafts and cars, etc. or other places where there is a need to profile complex contours accurately.

ACKNOWLEDGEMENTS

This research was supported by the National Science Foundation grants DMI-9871185, IIP-0637796, and IIP-0822739. Grant from NUTC is also greatly appreciated. Support from Product Innovation and Engineering, LLC, Missouri S&T Intelligent Systems Center, and the Missouri S&T Manufacturing Engineering Program, is also greatly appreciated.

REFERENCES

1. Hennesy RJ, Kinsella A, Waddington JL. 3D laser surface scanning and geometric morphometric analysis of craniofacial shape as an index of cerebro-craniofacial morphogenesis: initial application to sexual dimorph- ism. Biological Psychiatry 2002;51:507–14
2. Avdelidis NP, Delegou ET, Almind DP, Moropoulou A. Surface roughness evaluation of marble by 3D laser profilometry and pulsed thermography. NDT&E International 2004;37:571–575
3. Jong-Suk Yoon , MyungSagong , J.S.Lee , Kyu-sungLee , Feature extraction of a concrete tunnel liner from 3D laser scanning data, NDT & E International Volume 42, Issue 2, March 2009, Pages 97-105
4. Fabris M, Achilli V, Bragagnolo D, Menin A, Salemi G. Laser scanning methodology for the structural modeling. XXI International CIPA Symposium, Athens, Greece, October 1–6, 2007
5. Jun-Ming Lu, Mao-Jiun J. Wang, Automayed anthropometric data collection using 3D body scanners, Volume 35 , Issue 1-2 (July 2008) Pages: 407-414 , 2008, ISSN:0957-4174
6. Erhan Dikel, Cengiz Yener, A lighting coordinate database for 3d art objects ,Bilkent University, 06800 Ankara, Turkey,15 March 2006
7. Lee SJ and Chang DY. Laser scanning probe with multiple detectors used for sculptured surface digitization in reverse engineering. The 7th International Symposium on Measurement Technology and Intelligent Instruments, 2005. Institute of Physics publishing,: 155–8.

8. H. Bluteau , P.Bourdet , Quality follow-up of CMM via the measurements of microdefects. LURPA-ENS Cachan, 61 Av. du President Wilson, 94235 Cachan Cedex, France,12 April 2001.

9. Sparks T, Ruan J, Padathu A P, “Parameter space study for laser deposition”.