Three dimensional die repair using a hybrid manufacturing system

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ABSTRACT

A dramatic reduction in the cost, energy and time can be achieved by pursuing part repairing especially for die industry. In this paper, repairing process development was carried out by a hybrid manufacturing system aiming at the prevalent kinds of die core damages which is worn-out or corroded surface. Surface patches pattern is used for generating tool path to repair the damaged faces. A user-friendly software tool was developed to facilitate the users. 3D repairing technology was also integrated which ensures the alignment when more than one damages need to be repaired without reloading the part. Realization of 3D surface patching will greatly improve the accuracy, efficiency and reliability of part repairing. Verification and experimental results are also discussed.

INTRODUCTION

Part repairing technology has been applied in many industries, e.g. die manufacturing. Common processes used in part repairing technology are Gas Tungsten Arc Welding (GTAW) and Tungsten Inert Gag (TIG) welding. In our previous study [1], it was demonstrated that part repair can be done in a hybrid manufacturing system and the accuracy and reliability can be achieved as well. Here the hybrid manufacturing system includes Layered Manufacturing and CNC machining together and the resulting hybrid process can provide greater build capability and better accuracy and surface finish by achieving the benefits of both processes [2-4]. Layered Manufacturing method used in this paper is Direct Metal Deposition (DMD) process which utilizes the high power laser to melt metal powder layer by layer on the substrate to manufacture fully dense metal part directly. Compared with the traditional welding repairing technologies, the bonding strength of the repaired parts in a hybrid manufacturing system is higher than that of the welding process. In [1], hybrid manufacturing technology was adopted and the damaged features are replaced by machining the damaged feature out and depositing back the feature which we call feature replacing method later in the paper. Besides, for the toolpath generation, the contour offsetting toolpath was used for CNC machining also for laser aided deposition in [1]. In this paper, the strategy for repairing usual damages in die manufacturing which are the worn-out or corroded surfaces are studied. As far as worn out or corroded surfaces are concerned, there is not much to be pre-machined in preprocessing, and only very small amount of materials is needed to be deposited so as to cover the damaged area in a few layers. So surface patching method is much more effective, time saving, and cost saving than feature replacing method which will be explained and validated in the later sections.

Based on the surface patching method, the repairing job which involves more than one surface repairing is investigated as well. Obviously, 3D alignment needs to be integrated in the repairing process which ensures the feasibility and accuracy of repairing without reloading and setting up the part. The transformation principle will be discussed in the following section. By applying the transformation matrix, every damaged surface can be located exactly by multiaxial motion after the previous damaged face is finished and the repairing toolpath for every single damage surface will be connected in one automatic mode for the whole process. Meanwhile, the repair process planning software is developed to facilitate the users on VISUAL C++ programming platform, using ACIS as the modeling kernel and HOOPS as the graphics display engine.

PREVIOUS WORK

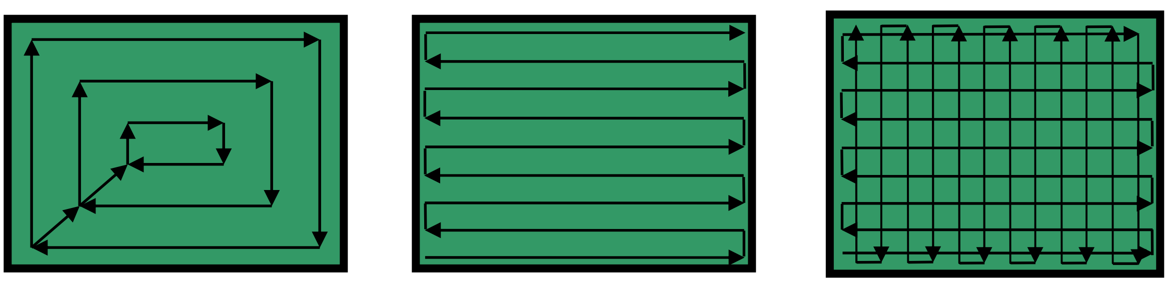
In literature, there are some particular repairing cases like repairing turbine blades and ship components [5-11]. In [1], a general repairing strategy was advanced and the basic idea is to repair the part by replacing the damaged feature. The process planning procedures are: 1) define the to-be-repaired feature, 2) generate the contour offsetting machining toolpath to machine out the damaged feature, 3) generate the contour offsetting depositing toolpath to deposit back the feature to the original, 4) post-process the toolpath data to get the CNC codes file for specified hybrid manufacturing system. In this strategy, the damaged feature is machined out and deposited back and then surface machining brings the whole repairing process to the end. Still there are two limitations about that work which will be improved in this paper. The first one is the limitation for repairing more than one damaged feature. The part has to be reloaded for the next damaged feature after each damaged feature is replaced because of lack of three dimensional alignments. Undoubtedly, this reloading will greatly decrease the quality of repairing job and also waste the time for setup. The other drawback is for worn out or corroded surfaces, pre-machining is not necessary which implies that replacing the damaged feature is not the best strategy to get repairing job done. Also the contour offsetting toolpath pattern sometimes can not guarantee the deposition quality because of the possibility of generating the porosity and bad surface evenness during deposition.

Aiming at the above limitations, surface patching method using adaptive zigzag toolpath pattern and three dimensional alignments are investigated especially for the basic types of damage in die industry in this paper. For worn out surface, the materials can be deposited on the damaged surface directly using the adaptive zigzag toolpath without pre-machining. The major difference between those two toolpath generation patterns will be demonstrated in details in the later section. In addition, transformation matrix will be integrated to automatically realize three dimensional repairing jobs in order to finally reduce the processing time and human interference and increase repairing reliability greatly.

SURFACE PATCHING METHODS

Surface patching method is a process planning strategy especially for repairing the worn-out and corroded surfaces by a hybrid manufacturing system which integrates laser deposition and

CNC machining together. It uses adaptive zigzag toolpath pattern for toolpath generation which changes the raster direction in the connective layers compared with traditional zigzag machining toolpath [12-13]. The following Figure 1 shows the difference among the contour offsetting pattern [14] and the traditional zigzag toolpath patterns along fixed direction and adaptive zigzag toolpath pattern for deposition along interlaced directions. As the figure demonstrates, the major difference between those two zigzag patterns is the travel direction. Instead of fixed direction in Figure 1 (b), the travel direction in Figure 1 (c) keeps switching in every connective layer, e.g. horizontal direction in the first layer and vertical direction in the second layer and then horizontal direction in the third layer again and so on. The other difference is that the boundary of the surface needs to be traveled firstly in adaptive zigzag pattern, then the offsetting surface area (the offsetting distance is usually the size of the laser spot) is filled by interlaced zigzag toolpath. The reason why the boundary of the original surface needs to be traveled firstly and then offset to get the target area for filling toolpath is because the extra materials will not be deposited on the boundary and the boundary won't be over-deposited as to destroy the surface evenness. Apparently, this will reduce the chances of occurrence of porosity. And as far as the traveling direction is concerned, usually the two principle axes of the target area are considered as the best choices.



(a) Contour offsetting (b) Zigzag (fixed direction) (c) Zigzag (interlaced direction)

Figure 1 Different tool path patterns

The following Figure 2 demonstrates the adaptive zigzag toolpath generated by the process planning software for the connective two layers of the triangular target are. The distance between these two layers is the layer thickness depending on the different hybrid manufacturing system's operation parameters. As shown, the target area is created by offsetting the original triangular surface and the toolpath for the bottom layer (Layer I) travel along horizontal direction, while the traveling direction for the top layer (Layer II) is vertical with previous travel direction.

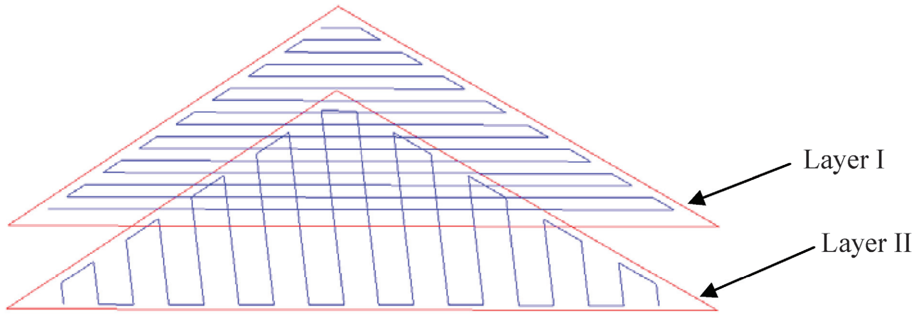
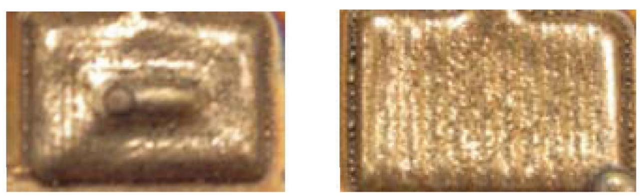


Figure 2 Interlaced zigzag toolpath in two connective layers

Figure 3 shows two deposition results of the same geometries got from two different toolpath patterns. In (a), the target geometry is filled by contour offsetting pattern and in (b) the toolpath pattern is the adaptive zigzag pattern discussed above. As shown in the figure, the surface evenness of (b) is much better than the surface evenness of (a). Also, figure 3(a) shows that there is a hump in the middle of the target area which often happens when depositing by contour offsetting pattern.



(a) Contour offset (b) adaptive zigzag

Figure 3 Depositions got from two different toolpath patterns

The advantage of this toolpath pattern is its feasibility and generality for curved surface which means it can follow the surface contour and act like the meshing grid of the curved surface. From another point of view, the adaptive zigzag toolpath even can be considered as the parametric curve expressions along two major axes which completely remain the surface contour information. The following Figure 4 shows the adaptive surface patching zigzag toolpath for curved face in both 2D and 3D modes generated by the repairing process planning software.

As the figure shows, 2D surface patch zigzag toolpath is generated by filling the projection area of the target face on X-Y plane and it actually loses most information about the target curved surface. Different from 2D surface patch, 3D surface patch keeps almost all the feature information of the target surface and definitely will cause the better deposition quality in most situations. Weather or not to use 3D surface patch actually depends on the curvature of the curved surface. Experimental results prove that the deposition quality almost stays same when using either 2D or 3D surface patch if the curvature is not very high. While for high curvature, deposition using 2D surface path is not even successfully and 3D surface patch undoubtedly is the optimal strategy.

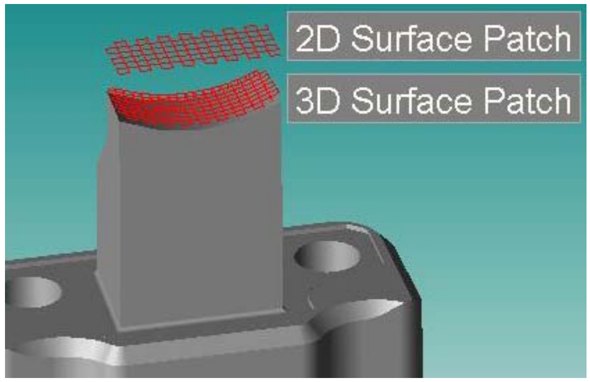


Figure 4 Surface patching zigzag toolpath for curved surface

Toolpath Generation for Complicated geometry

About toolpath generation method, there is one more issue investigated in this paper which is the toolpath generation strategy for complicated geometries. For the certain complicated shapes which include inner loops or concave vertex, in order to avoid crossing the loops, the geometry needs to be divided into several sub-regions among which any one has no inner loops or concave vertex. Then every sub-region will become the target area and the same toolpath generation method is used like discussed above to get reasonable zigzag toolpath separately. Here cell decomposition algorithm [15-16] is adapted to divide the target area into different sub-regions which are then filled by adaptive zigzag toolpath pattern. After the target area is broken into sub-regions, the same toolpath generation algorithm is used for every sub-region, and the boundary for every sub-region needs to be traveled before filling with zigzag toolpath to guarantee the inner loops features.

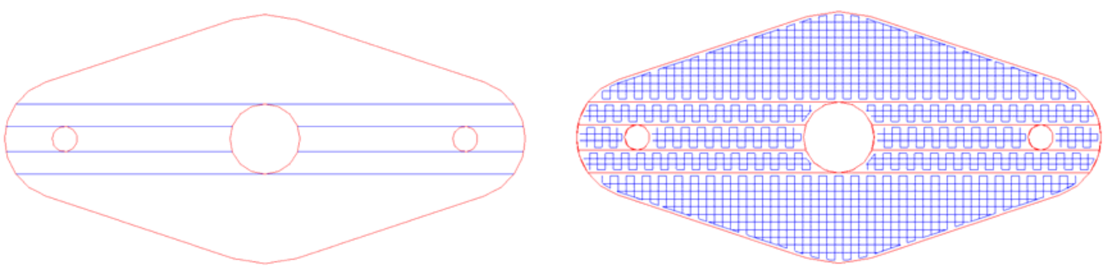


Figure 5 complicated geometry broken into subcomponents covered by zigzag toolpath

As shown in Figure 5, the total toolpath for the complicated geometry divided into n sub-components is the summation of the toolpath for every single subregion. As far as the connection toolpath among all the subregions, the rapid travel lines are applied to realize the transition from one subregion to the next.

3D SURFACE PATCHING REPAIRING

3D repairing means repairing more than one damaged faces automatically where alignments are integrated in order to guarantee the accuracy and reliability of repairing job without reloading the part and human interference. Because of the translational and rotational movement needed, the transformation matrix is necessary to get CNC codes for transformational motion besides the regular zigzag toolpath for every damaged surface.

In this paper, the FADAL five-axis CNC machine used in LAMP lab consisting of an X-Y table, a movable Z axis and an A and B rotary axes are studied. The coordinates of rotation center which is the intersection point of A and B axes are measured by factorial experiments by advance. Suppose there are *n* damaged surfaces to be repaired in certain order which can be determined by the user, the surface normal for every damage surface needs to be found so that after certain transformational movement, the damaged surfaces can be located at any position and direction. Then the part will be transformed and relocated to the destination where the next to-be-repaired surface is perpendicular to the Z-axis which is the direction of the laser nozzle. Based on the information of rotation center, every intermittent position and transformation matrix for each damaged surface can be calculated. It is possible to predict the position and orientation of the workpiece after arbitrary rotations of A and B axes and rotational axis commands will interpret all the rotational motion along A and B axis. Because the CNC controller can realize the location of the part at any position within the machine work range, the process planning can be finished for the whole repairing task automatically in one setup which greatly enhances the accuracy and reliability and reduces the repairing time.

EXPERIMENTS

The repairing strategy discussed above has been applied on the mold/die repair for Spartan Light Metal LLC. Figure 6 shows the damaged die core before repairing and after deposition by surface patching strategy. The top of portion of the die is damaged and all the surrounding worn out surfaces need to be repaired. Here the surface patching pattern was used to generate the adaptive zigzag toolpath and 3D transformation was included here also to finish repairing all the surrounding damaged surfaces in an automatic mode without human interference. The whole repairing job was finished in one setup. The laser used was NUVONYX 1K max diode laser. The laser processing parameters for cladding steel H13 powder were 600W with a stand off distance from the nozzle to the top of the clad of 0.5 inch. The powder feed rate for H13 powder was 6g/min. The NC code was set to move the nozzle up 0.02 inch after each layer which is the layer thickness mentioned above. The travel speed of the nozzle was 20 inches/minute and the track width is 0.05 inch.

(a) Before repairing (b) After deposition (c) After surface machining

Figure 6 Die core repaired via 3D surface patching

Figure 7 shows three moments to repair three different damaged surfaces respectively. The whole repairing job only took less than 10 minutes except the time for setting up the part which proves much more effective compared with the feature replacing method for repairing corroded or worn-out surfaces.

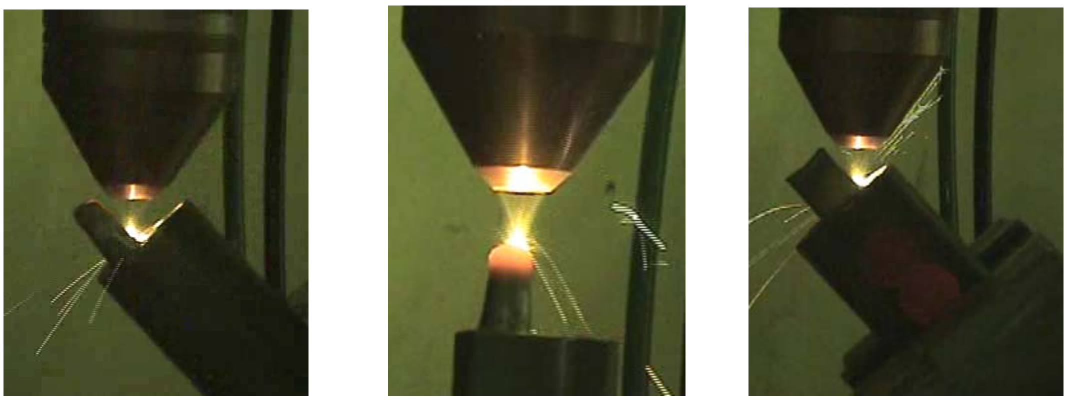


Figure 7 Automatic repairing processes

In the previous study [1], it was proved that the bonding strength of the repaired parts in a hybrid manufacturing system is better than that of welding process. In addition, another very important mechanical property for mold/die repair is the thermal conductivity. By making electrical resistance measurements, the thermal conductivity measurements can be made. The test results in the following Figure 8 shows that the deposition repair has the better thermal conductivity. Furthermore, the most practical evaluation is to test the repaired part in the real engineering environment. And the above repaired die has been tested by Spartan Light Metal LLC and the result is very satisfying.

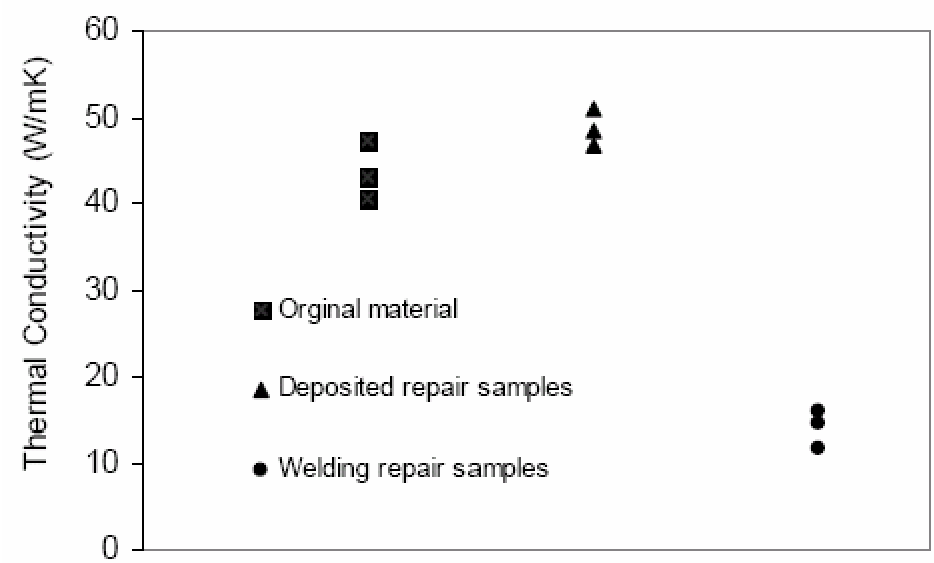


Figure 8 Thermal conductivity comparisons

CONCLUSION

Surface patching method is an effective strategy to repair the usual kinds of damages in die industry with high reliability. Compared with replacing damaged features, surface patching saves time, energy and cost dramatically. And the adaptive zigzag toolpath generation pattern can greatly improve the deposition surface evenness and the repairing quality as another optional pattern in layered manufacturing. The integration of 3D alignment can guarantee the accuracy and reliability of repairing job and the accomplishment of the whole repairing process in a completely automatic mode for multiple damages without human intervention. For the complicated geometry divided into subcomponents, the deposition sequence among all the subcomponents is another research issue. In this paper, the transition among all the components is traveled rapidly. The optimized sequence will definitely enhance the deposition quality.

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