Microstructural Properties of Al-Cu-Mg Taylor-made functionally graded layer by Friction Stir Additive Manufacturing

Sarvesh Kumar[1], Ashish Kumar Srivastava[1,2*]

[1]Department of Mechanical Engineering, Shri Venkateshwara University Gajraula, Amroha, U.P. India
[2]Department of Mechanical Engineering, G. L. Bajaj Institute of Technology and Management, Greater Noida U.P. India

Abstract

Additive Manufacturing (AM) is among the most sort after manufacturing technique. There are various AM techniques in industries but to reduce the gap between the properties desired by the industries and properties offered by the various techniques Friction Stir Additive manufacturing (FSAM) is considered as emerging option. FSAM method is emerging techniques of AM that utilizes the idea of friction stir processing and friction stir welding to create multilayer segments by joining one layer on top of another layer. This technique helps to achieve superior and modified properties like no internal cavity, no shrinkage and high dimensional accuracy. In the present paper, work has been done to analyse the microstructural properties of Al-Cu-Mg composite. Improved strength by grain refinement was observed with lest defects.

Keywords: *Friction Stir Additive Manufacturing (FSAM), Friction Stir Welding (FSW), Microstructural Behaviour.*

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1. INTRODUCTION

Additive Manufacturing (AM) includes developing of 3D parts as a rule of one layer over the other layer expansion of substance straightforwardly by a PC supported planned specimen [1]. Generally, AM utilizes present-day innovation like CAD, CNC, and simulation programming for creating various categories of materialistic articles throughout the most recent couple of years [2]–[4]. Various contact-based procedures have been created, changed and read for their reasonability as AM innovation. Because of their activity on the solid state, rubbing based added substance fabricating also called Friction Based Additive Manufacturing (FBAM)[5].It has certain preferences over regular AM strategies, a couple of which are non-attendance of porosity/absconds in the completed section, a decent equilibrium of mechanical properties, and low degree of leftovers [6]. AM empowers climate neighbourly item configuration too. Dissimilar to customary assembling measures that place numerous limitations on item plan, the adaptability of AM permits makers to upgrade plan for lean creation, which by its inclination dispenses with squander. Moreover, AM's capacity to build complex calculations implies that numerous recently isolated parts can be solidified into a solitary article. Moreover, the topologically improved plans that AM is fit for acknowledging could expand an item's usefulness, in this manner diminishing the measure of energy, fuel, or characteristic assets needed for its activity [7]. The item created by AM strategy has colossal preferences like less material just as power misapplication contrasted with conventional techniques. The cycle is fit for creating a better standard item having amazing dimensional exactness and substance properties [8]. Now our work in particular deals with FSAM and to prove that the component produced by FSAM have significant development over base material or if it was manufactured by some other technique. The benefits of any work on FSAM is that the process itself has no ugly consequences on environment i.e. no harmful gases so it's a safe and sound process for both human and nature[9]–[11].The main aim of the paper is to show that apart from being environment friendly the process also produce material with advanced mechanical and microstructural properties.The project work not only intend to add another proof of superiority of FSAM process but also it aims to find outoptimum method or condition for production of superior component in terms of mechanical and microstructural properties. The component manufactured by FSAM will itself be a combination of different material or may be different design and tool parameters in order to produce a superior component with exceptional properties in comparison to its raw material and other advanced mechanical components. We all are familiar with different phases of industry and right now industry is in phase known as Industry 4.0 [12]and it depends highly on Additive Manufacturing and in that also it depends mostly on 3D printing. It is known that although 3-Dimensional printing is a revolutionary technology but it fails when component with high structural strength is needed to be produced. The project aim is to gives a new process which can produce material with high mechanical and microstructural properties. The work will attempt to stablish a less known method of Additive Manufacturing called Friction Stir Additive Manufacturing as a superior technique. We also aim to show the materials considered as non-processable or are not machinable or have high melting point can also be used after finding out the ideal way with proper variables and controls after Friction Stir Additive Manufacturing is established as ideal process. Also, Figure 1 is showing the importance of FSAM in form of its contribution in various industries.

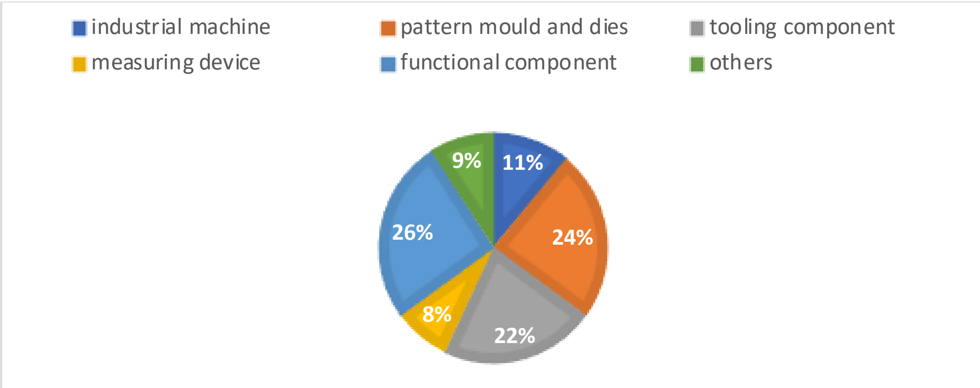

Figure 1. Estimated contribution of Friction Stir Additive Manufacturing in various fields

2. EXPERIMENTAL PROCEDURE

Selection of sheet material is an important task to perform he FSAM. Based on the literature survey, the material chosen for joining purpose are plates of Aluminium, Copper and Magnesium of 2-3 mm thickness. The specifications of materials are given in Table1. The materials are selected for their good structural properties and also because these are widely used and abundant materials.

Table 1. Materials and their Mechanical properties

Material	Density (g/cm3)	Modulus of Elasticity (Gpa)	Tensile Strength (Mpa)	Yield Strength (Mpa)	Thermal Conductivity (W/(m·K))	Melting Temperature (°C)
AZ91	1.81	45	250	160	72	533
Cu	8.95	117	221	138	391	1085
Al-7075	2.81	71.7	572	503	196	556

The substrate of the base material is cast iron. The selection of cast iron depends on its high ability to absorb energy and also the ability to deform without fracture. It also has ability to regain its original shape after the release of load. To develop the substrate, first select a base to hold or support the plates. A proper base of cast iron was selected after the selection of the base we make the fixture holes on the base plate for the proper fixing of the plate over the base. We created 8 holes of 8mm with the help of a drilling machine after that two steel strips with 8mm holes on both sides are created on a band saw. 4 Nuts and 4 bolts to fasten the steel strip to hold the plates over the base plate were used. Figure 2 shows the drilling operation, drilled base plate and complete fixture arrangement used in this study.

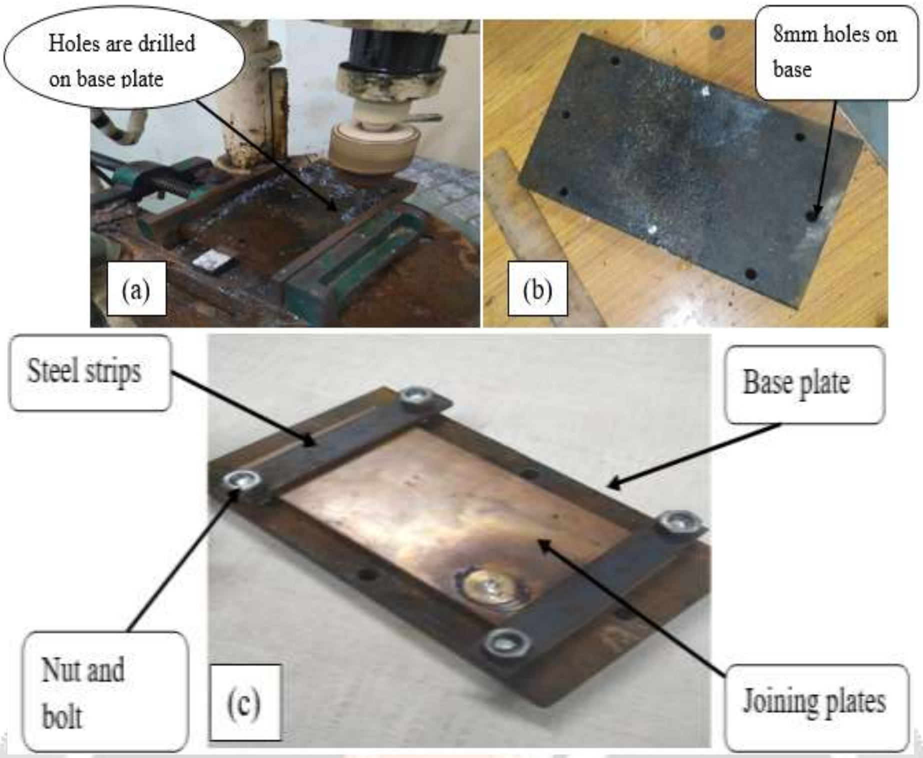

Figure 2. (a) Drilling on the base material, (b) Drilled base (c) Complete fixture

The tool is made of high-speed steel to complete the FSAM process on the plates by the use of milling machine. HSS is used because it can withstand higher temperatures without losing its temper (hardness), it also exhibits high strength and hardness but typically exhibit lower toughness. Figure 3 shows the HSS tool with threaded pin design and physical image of tool during the FSAM operation whereas various tool parameters are shown in table 2.

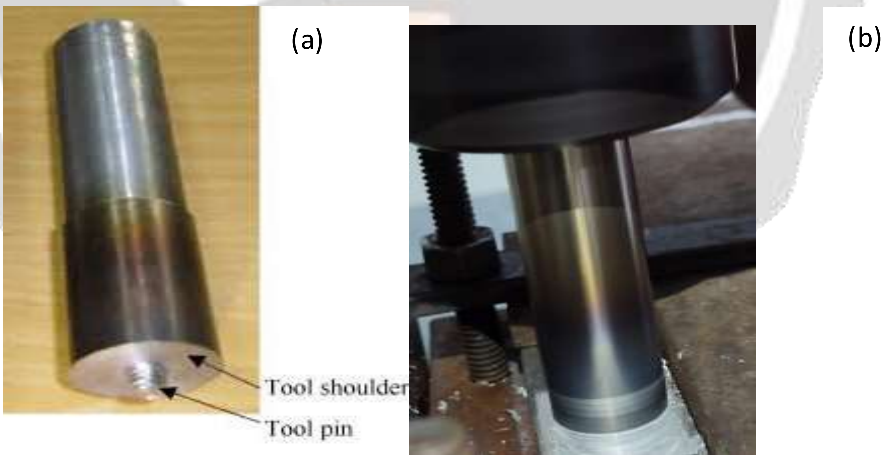

Figure 3. (a) HSS tool used for the process (b) Tool during the process

Table 2. Process and tool parameters

Rotational Speed (rps)	Transverse speed (mm/min)	Tilt angle (degree)	Shoulder Diameter(mm)	Tool pin shape	Tool pin diameter (mm)
2000	40	0	11.8	cylindrical threaded	4

Design parameters play a crucial role in attaining the desired result for the project. After the review of previous work various parameters affecting the properties of the manufactured component were identified e.g. rotational speed of tool, tilt angle, transverse speed, shoulder diameter of the tool, tool pin shape and tool diameter. After understanding their relationship with the properties of the manufactured component a suitable range of parameters was selected. Table 2 shows the combination of process and tool parameters used in this study. These values are selected on the basis of pilot experiments. This combination will be used in order to achieve the satisfactory result by trying and applying them until it gives a satisfactory result.

Microstructural properties like porosity, inclusion, particle segregation, cavities, homogeneity etc. would be checked by microstructural evaluation of the component. In analysis techniques such as Scanning electron microscopy (SEM) and Transmission electron microscopy (TEM) would be used.Mechanical properties like hardness, tensile strength, fatigue strength needs to be measured by proper tests and various graphs of micro-hardness variation, load-displacement curve, stress-strain curve need to be made for proper examination. After conducting various tests and evaluating the microstructural and mechanical properties of component prepared is compared with the properties of material produced by other techniques. Incase properties and features of the component produced by Friction Stir Additive Manufacturing are better than component produced by other processes and also solves the problems like internal porosity, anisotropic nature, inclusion, shrinkage, non-homogeneity etc. then the experiment is successful and desired result are obtained. If the component analysis does not show desired result, then the variable parameters like material selection, various process parameters (like tool speed, force applied etc.) are changed above methodology is repeated again until satisfactory results are obtained.

The microstructure test has been performed to understand the microstructure changes in the individual material used to design the composite by friction stir additive manufacturing method. Optical microscopy setup was used to perform this test (Figure 4). On this machine we get the microstructure of the joined component when two plates are joined and when all of the three plates are joined. Also, we get the grain size of the component which we produced on the vertical milling machine by the use of the method of the friction stir additive manufacturing.The tests have been performed alsoto understand the changes of microstructure at the boundaries of Aluminium/Copper and copper/magnesium. We have also understood the changes of microstructure on the Aluminium surface after the application of friction stir processing.The Grain size of Aluminium and copper have been also determined.

Figure4. Microstructural grain size testing machine

3. RESULTS AND DISCUSSION

When all the processing is done on the milling machine, all three plates were successfully joined as shown in Figure 5. All three plates are completely joined together through Friction stir additive manufacturing (FSAM) technique or method.

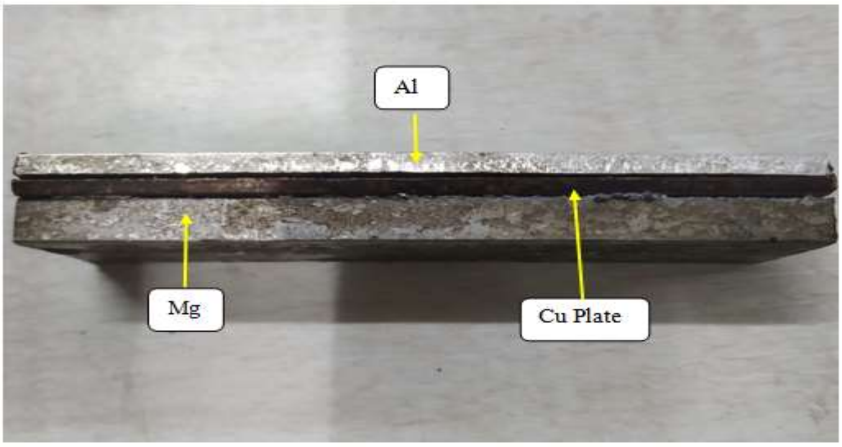

Figure5. Joined plate after FSAM is completed

It is observed from the physical observation that the plates are strongly joined to each other at the stir zone and have negligible defects like tunneling. However, more efforts have been applied to join the copper plate with magnesium because of temperature difference. The successful operation was reported at the higher dwelling time in the copper plate. While joining the Aluminium layer, the effect of frictional heat also affects the previously joined layer and there are major microstructural changes were observed below the recrystallize temperature. Once the samples were prepared, the specimens for microstructural observations were prepared from both Al-Cu and Mg-Cu layer. The microstructural changes in Aluminium, Copper and Magnesium were also observed to show the grain size and other microstructural observation after FSAM process.

Figure 6 shows the microstructure report of Al-7075 plate after joining with copper plate. It is observed from the image that no any major defect is observed and the grain structure is equiaxed and homogeneous. Large number of grain boundaries are also observed due to grain refinement technique of FSAM. The microstructure report reported the FeAl2 insoluble particles and can be seen in black colour.

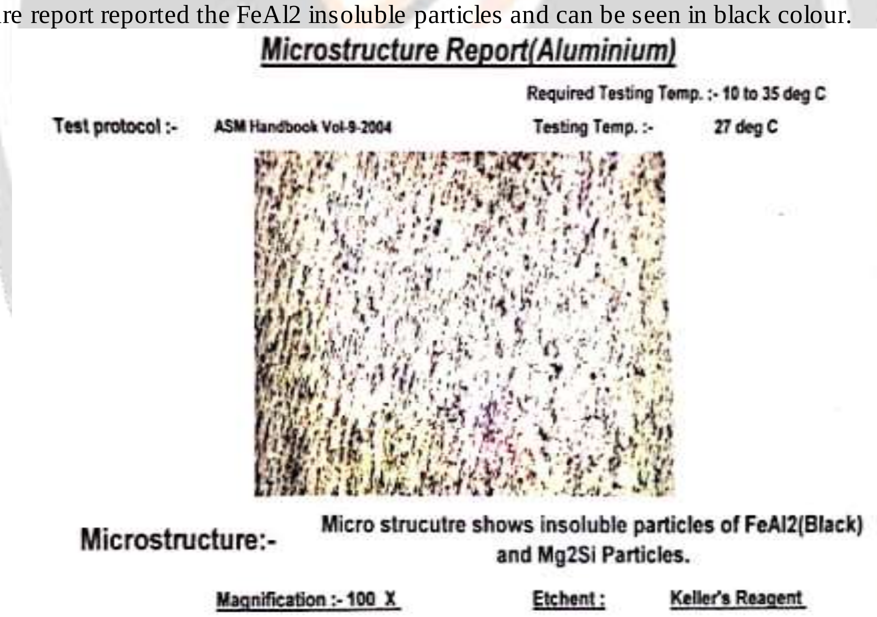

Figure6. Microstructure report of the Aluminium and its grain structure

Figure 7 shows the microstructure report of Magnesium plate after FSAM operation taken at 100X magnification. It is observed from the image that no any major defect is observed and the grain structure is equiaxed and homogeneous. Large number of grain boundaries are also observed due to grain refinement technique of FSAM. The black color insoluble particles can be also seen from the microstructure image. In comparison to Aluminium, the grains of magnesium are more refined and equiaxed. It is attributed to the fact that the magnesium is experienced with two times frictional heating process. The first is introduced at the time of joining of first layer (Copper) and Second time while joining the Aluminium layer over the copper layer. Hence, the microstructural change are more compared to aluminum layer.

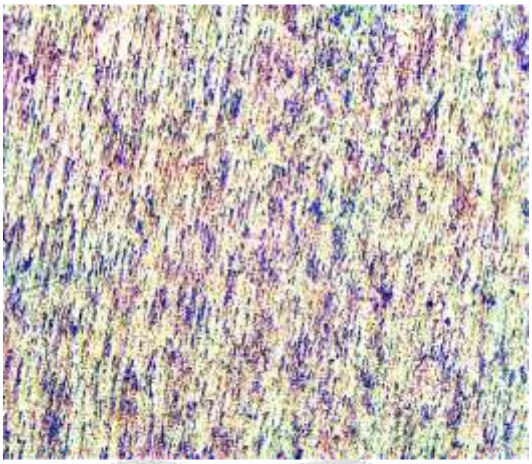

Figure 7. Microstructure report of the Magnesium and its grain structure

Figure 8 shows the grain size report and microstructure of Copper plate after FSAM processtaken at 100X magnification. It is observed from the image that no any major defect is observed.

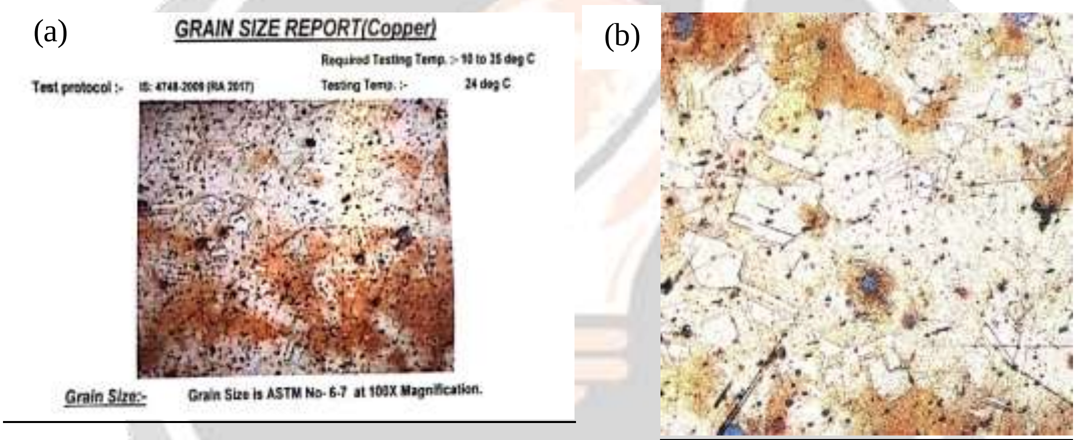

Figure 8. (a) Microstructure report of the copper and its (b) grain size image

Large number of grain boundaries are also observed due to grain refinement technique of FSAM. The black colour insoluble particles can be also seen from the microstructure image. However, in copper plate the grains are not seen homogeneous and also non uniform. It is attributed to the fact that due to the non-severe plastic deformation and insufficient effect of frictional because of high melting temperature of copper, the time to get solidify below recrystallization temperature is short, hence the particles are disoriented randomly.

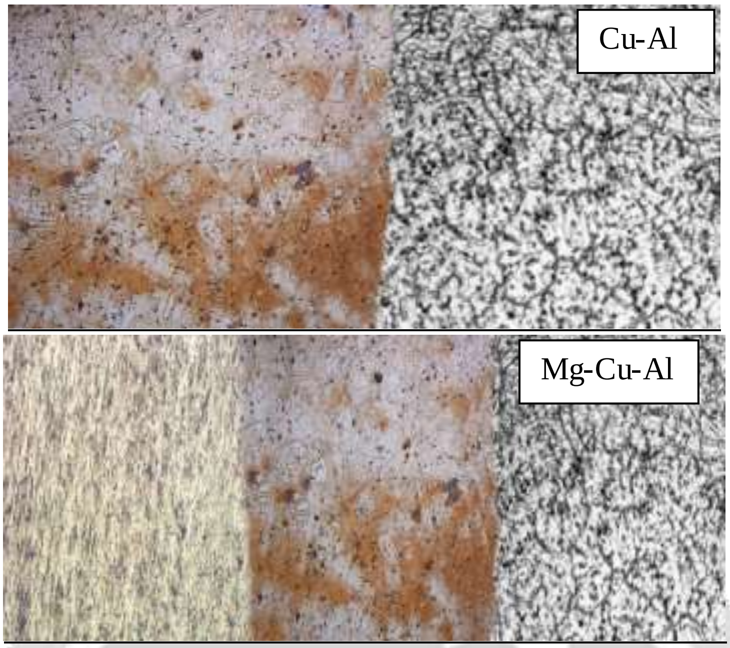

Figure 9. Microstructure at the boundary of (a) Mg-Cu (b) Cu-Al (c) Mg-Cu-Al

Figure 9 (a-c) shows the microstructural images taken at joints of three plates Mg-Cu-Al. It has been observed from the images that there are no major defects were observed near the joints and are successfully immerged into each other. No clearance, blow holes and voids are seen through the microstructural images. Large number of grain boundaries are also observed due to grain refinement technique of FSAM. It is also observed that magnesium and aluminium plates are subjected to severe plastic deformation. However, copper is not completely defused with Aluminium or Magnesium. It is attributed to the fact that due to the non-severe plastic deformation and insufficient effect of frictional because of high melting temperature of copper, the time to get solidify below recrystallization temperature is short, hence the particles are disoriented randomly.

4. CONCLUSION

In this study, an Al-Cu-Mg composite is fabricated using friction stir additive manufacturing. The microstructure and mechanical properties of the laminated composites wereinvestigated. In the tensile test, the result has shown that our specimen has bear a peak load of 2334.1 N before fracture. The peak displacement value is 2.10 mm. The stress was 64.8 N/m^2 at strain 0.1. In microhardness Vickers test three indents have been made at 300 grams load and the hardness number are 64.8, 67.5 and 65.2 respectively. The average hardness number is 65.83 HV. In the microstructural test, the grain size and microstructure of the component has been determined. From the experiment we have understand the importance of friction stir additive manufacturing. We have also understood that AM process is not well suited to industrial applications. Further research should be required to explore its feasibility in the field of manufacturing. FSAM is useful in the production of high-performance component. We can also customize the build performance by controlling the microstructure of the component designed by friction stir additive manufacturing. We can also preheat the component by laser source before processing to soften the material for pin and also reduces the tool forces. To improve the mechanical properties of the component many different changes could be made. The changes like weld parameters can reduce defects like porosity and cracks. The heat treatment temperature could be used with some type of moderate quenching rate. This may harden the microstructure and create stronger material properties. As discussed above even if we have not got the satisfactory result in tensile test and microhardness test we can improvise it by selecting different high grade material. Instead of manual milling machine we can use robotic milling machine. We can also improve our result by changing the machine specification, tool pin shape and also the machine operator skill should be improved to achieve desired result.In all, the additive manufacturing process described in this report shows promising results thatcould be further improved with small process enhancement. This process could be an effectivetool to save time and production costsin an industrial application. With further research anddevelopment on this topic, additive friction stir manufacturing could be put into application.

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