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Abrasive flow machining: a case study

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INTRODUCTION

Abrasive Flow Machining (AFM) is used to deburr, polish or radius surfaces and edges by flowing a semisolid abrasive media over these areas. The process embraces a wide range of feasible applications: from critical aerospace and medical components to high production volumes of parts. AFM can reach even the most inaccessible areas, processing multiple holes, slots or edges in one operation. Advances in media formulation and tool design coupled with new capabilities in processing and automation have established the abrasive flow process as a way of satisfying tough manufacturing requirements economically and productively.

The AFM process can be used in a wide range of finishing operations. It can process many areas on a single workpiece or multiple parts simultaneously. Inaccessible areas and complex internal passages can be finished economically and productively. Automatic AFM systems can handle thousands of parts per day, greatly reducing labor costs by eliminating tedious hand work. By understanding and controlling the process parameters, AFM can be applied to an impressive range of finishing operations, providing uniform, repeatable, predictable results.

In abrasive flow machining two opposed cylinders extrude a semisolid abrasive media back and forth through passages formed by the workpiece and the tooling (Figure 1). The process is abrasive only where the flow is restricted: the extrusion area. The machining action compares to a grinding or lapping operation as the abrasive media gently and uniformly hones the surface or edges. Materials from soft aluminum to tough nickel alloys, ceramics and carbides can be successfully micro-machined with this process.

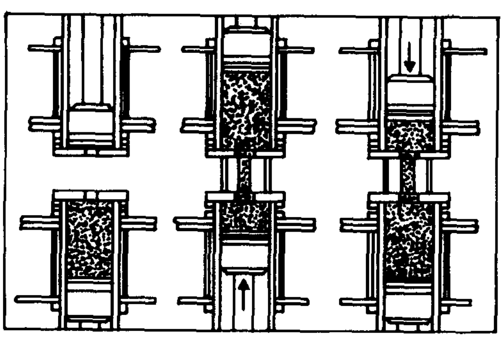

Figure 1 - Abrasive Flow Machining Process

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Extrusion honing-or AFM-can be applied to achieve a wide range of predictable, repeatable results. If the objective of AFM involves uniformly polishing the walls of the restricting passages, in die polishing for example, the media chosen should maintain a uniform flow rate as it is extruded through the passage (Figure 2). For deburring or radiusing the edges of a passage, a less viscous media that increases flow rate once it enters the passage causes the edges to be abraded more than the passage walls (Figure 3). The type of flow pattern that occurs depends on the machine settings, the media formulation, and the workpiece and tooling configuration.

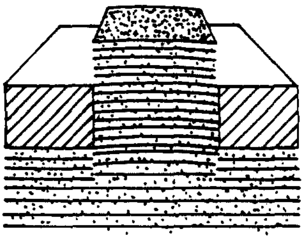


Figure 2

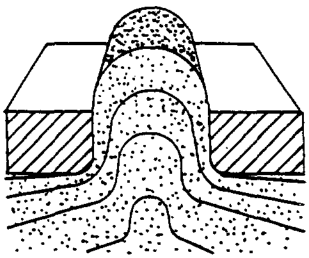


Figure 3

The media flow pattern can be varied to achieve different finishing results.

PROCESS PARAMETERS

Machine

The abrasive flow machine, available in a variety of sizes, contains two vertically opposed media cylinders which hydraulically close to hold a part or fixture between them. By repeatedly extruding media from one cylinder to the other, an abrasive action is produced wherever the media enters and passes through a restrictive passage as it travels through or across the workpiece (Figure 4).

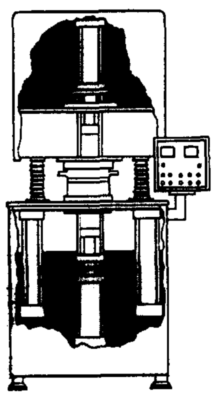


Figure 4 - Abrasive Flow Machining System

The machine also controls the extrusion pressure. Machines are available with extrusion pressures that range from 7 to 220 bar (100 to 3200 psi) with flow rates exceeding 380 liters (100 gallons) per minute. The volume of flow depends on the displacement of each media cylinder stroke and the total number of stroke cycles used to complete the job. These variables are both preset at the machine.

Control systems may be added to monitor and control additional process parameters such as media temperature, viscosity, wear and flow speed. AFM systems designed for production applications often include part cleaning and unload/reload stations, media maintenance devices and cooling units. These automated systems can process thousands of parts per day with processing times typically ranging between one and three minutes for each pallet loaded with workpieces (Figure 5).

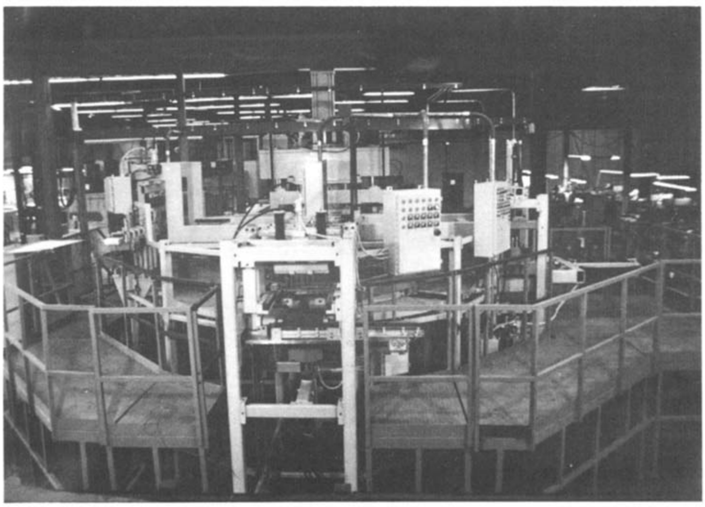


Figure 5 - This automated AFM cell deburrs and polishes automotive armature shafts. The system processes 49 parts per fixture in less than 2 minutes and is equipped with automatic burr qualification, part loading, unloading and cleaning.

Tooling

The tooling holds the workpiece in position and directs the abrasive media to the appropriate areas. Many AFM applications require only simple fixturing: dies typically need no special tooling; the die passage itself provides the restriction for the flow path. For external edges or surfaces, tooling is used to restrict the flow between the outside of the part and the inside of the fixture (Figure 6). The tooling may also serve to restrict flow at areas where abrasion is desired or to block the flow through areas to remain unaffected.

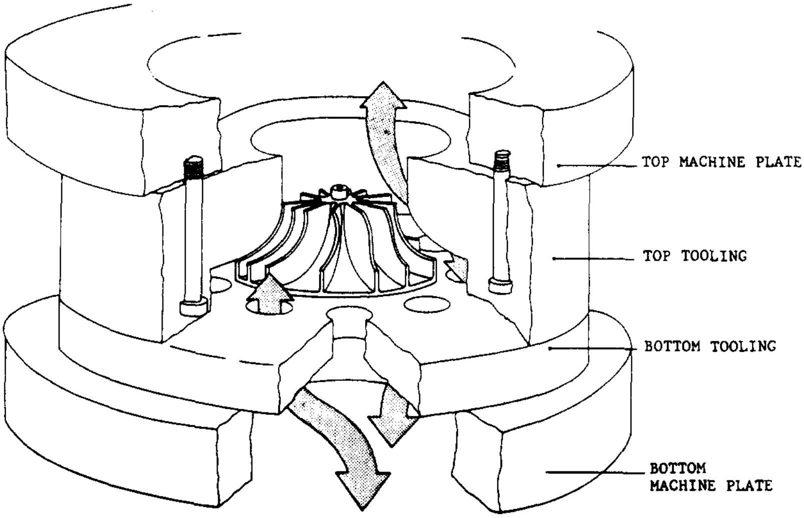


Figure 6 - For processing external edges, the part is contained within a fixture to form a flow restriction between the outside of the part and the inside of the fixture.

High production fixtures are designed to facilitate part loading, unloading and cleaning. Often mounted to indexing tables, these fixtures may hold multiple parts for processing in one operation (Figure 7).

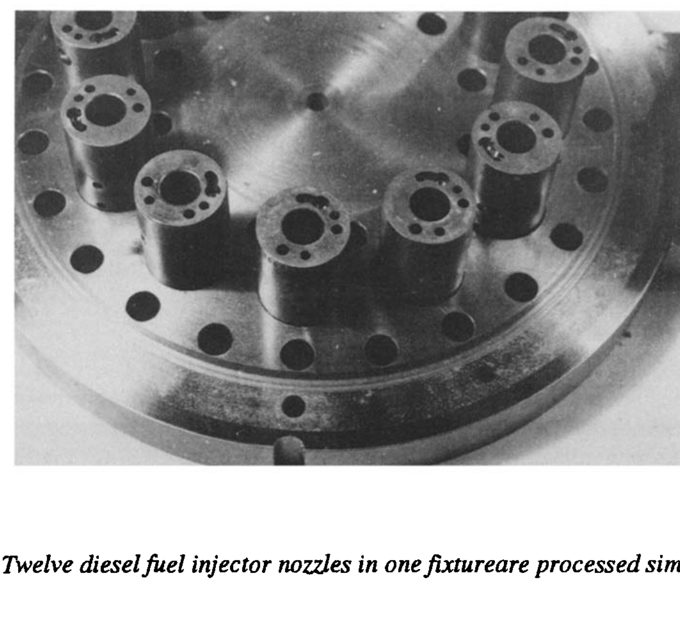


Figure 7 - Twelve diesel fuel injector nozzles in one fixtureare processed simultaneously.

Media

The media is composed of a pliable semisolid carrier and a concentration of abrasive grains (Figure 8). The viscosity of the carrier and the abrasive grain size, type and concentration can be varied to achieve specific finishing results. Higher viscosity, nearly solid media is used for uniformly abrading the walls of large passages. Lower viscosity media is generally appropriate for radiusing edges and for processing small passages. When forced into a restrictive passage, the viscosity of the media temporarily rises, holding the abrasive grains rigidly in place. The media abrades the passages through which it flows only when in this viscous state. The viscosity returns to normal when the thickened portion of media exits the restrictive passage, producing little or no abrasion.

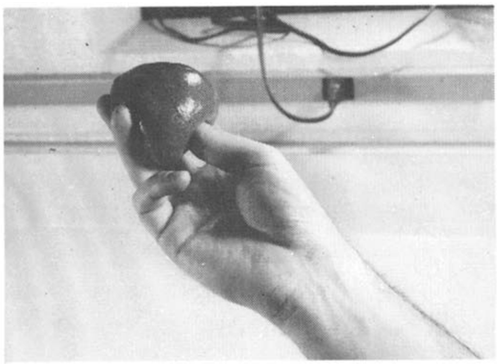


Figure 8 - A central element of the AFM process is the media, a polymer carrier mixed with abrasives.

Media viscosity, extrusion pressure and passage dimensions determine the media flow rate (the speed of the abrasive slug passing through the restrictive passage) which affects the amount of abrasion, the uniformity of stock removal and the edge radius size. The flow rates are calculated by dividing the flow volume by the processing time. Slow slug flow rates are best for uniformly removing material; high slug flow rates produce larger edge radii.

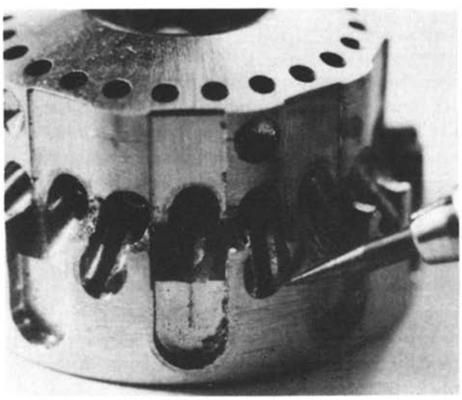
If the passage length is substantially smaller than two times the passage width, a higher viscosity media or lower extrusion pressure should be used. Conversely, if the passage length is substantially greater than two times the passage width, a lower viscosity media or higher extrusion pressure is required. As the media temperature increases during processing, its viscosity decreases, thus extending the passage size range of a given media.

The abrasive grains are most commonly made of silicon carbide, although boron carbide, aluminum oxide and diamond may also be used. Particle sizes range from 0.005 mm to 1.5 mm (0.0002 to 0.060 in.). The better the starting finish, the smaller the grit size used for processing. The larger abrasives cut at a faster rate, while the smaller sizes provide finer finishes and accessibility to small holes. The depth of cut made by the abrasive grains at the surface depends on the extrusion pressure applied and on the stiffness of the media as at the surface depends on the extrusion pressure applied and on the stiffness of the media as well as on the size of the abrasive grains. Air or vacuum may be used to remove the media from accessed areas. Final traces can be extracted in a solvent wash.

In the AFM process, the abrasive cutting particles break and become dull, and the abraded material becomes part of the abrasive media. The effective life of the media depends on a number of factors including the initial batch quantity, the abrasive size and type, the flow speed and the part configuration. Typically a machine load of media can be used for weeks, processing thousands of parts, before replacement.

PROCESS APPLICATIONS

AFM offers precision, consistency and flexibility to a wide range of applications in aerospace, automotive, production and die finishing. Other applications have been developed in areas as diverse as surgical implants and centrifugal pumps. The process was initially developed to perform critical deburring of aircraft valve bodies and spools, providing burr free internal edges, routinely passing 20X microscopic inspection while producing precisely controlled edge radii. The turbine fuel spray nozzles pictured below are shown before (Figure 9) and after (Figure 10) processing.



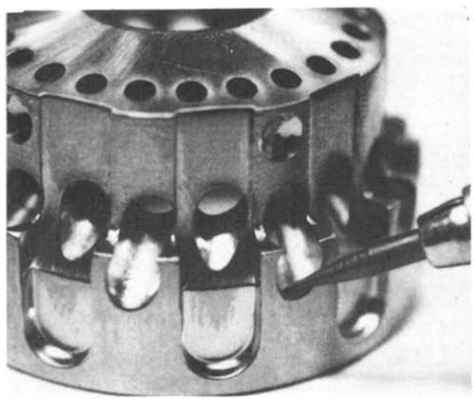


Figure 9 *Figure 10*

Turbine engine fuel spray nozzles use AFM to satisfy critical deburring requirements.

The AFM process can be applied to a wide range of part and passage sizes-from gears as small as 1.5 mm (0.060 in.) in diameter and orifices as small as 0.2 mm (0.008 in.) to splined die passages 50 mm (2 in.) in diameter. One of the primary advantages of the extrusion honing process lies in the uniformity of the polished surface, especially when compared to tedious, manual finishing methods. This advantage leads to other benefits directly associated with lower labor costs with improved part performance, longer life, less scrap and rework and reduced inspection times. In the pendulum for an accelerometer shown in Figure 11, the recast left by EDM was removed in 180 slots, 0.15 mm wide (0.006 in.), 1.5 mm long (0.060 in.), with a wall thickness of only 0.25 mm (0.010 in.).

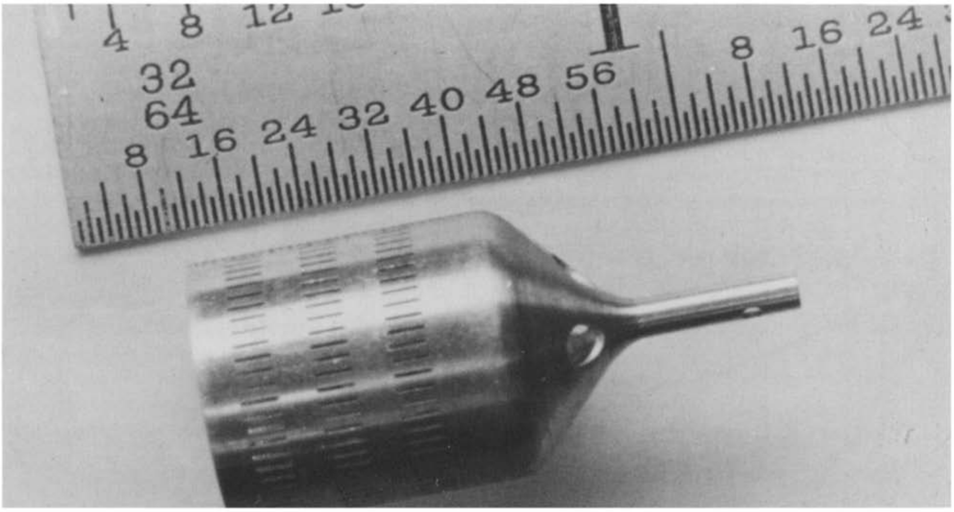


Figure 11 - Variable extrusion pressures permit even fragile components to be reliably processed.

Some additional AFM applications in aerospace include removal of the thermal recast layer in the lasered or EDM'd cooling holes of blades and disks, deburring fuel spray nozzles, and polishing cast surfaces of blades, compressor wheels and impellers (Figure 12).

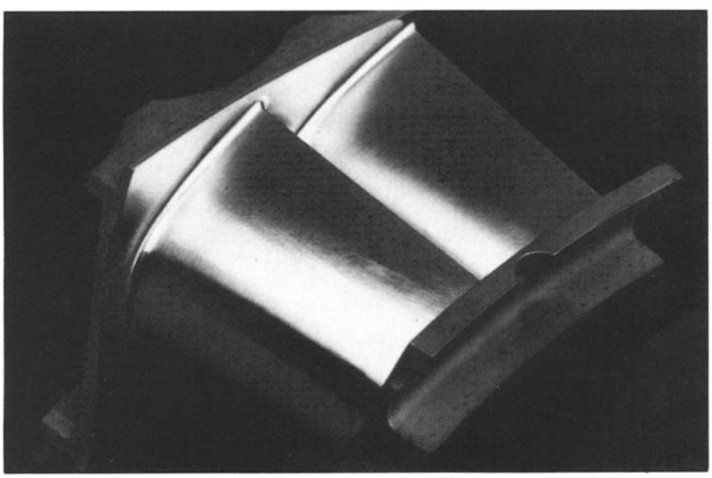


Figure 12 - Uniform, controlled stock removal improves the surface finish of cast blades with minimal dimensional change.

Extrusion honing is used to polish a variety of dies for extruding, drawing, forging, cold heading and compacting, eliminating the expense and inconsistency of handwork. Uniform, controlled stock removal permits accurate sizing of die passages with minimal dimensional change. Typically, original EDM'd finishes of 2.5 μM R_a (100 μinch) are polished to below 0.25 μM R_a (10 μinch) in a ten minute cycle without special tooling requirements. Surface finish improvements to one tenth the original finish are generally expected from the process in such applications.

The multi-port aluminum extrusion die shown in Figure 13 used AFM for improving the EDM finish of 1.9 μM R_a (75 μinch) to a 0.18 μM R_a (7 μinch) in a five minute cycle. A close-up of the teeth is shown before (Figure 14) and after (Figure 15) processing.

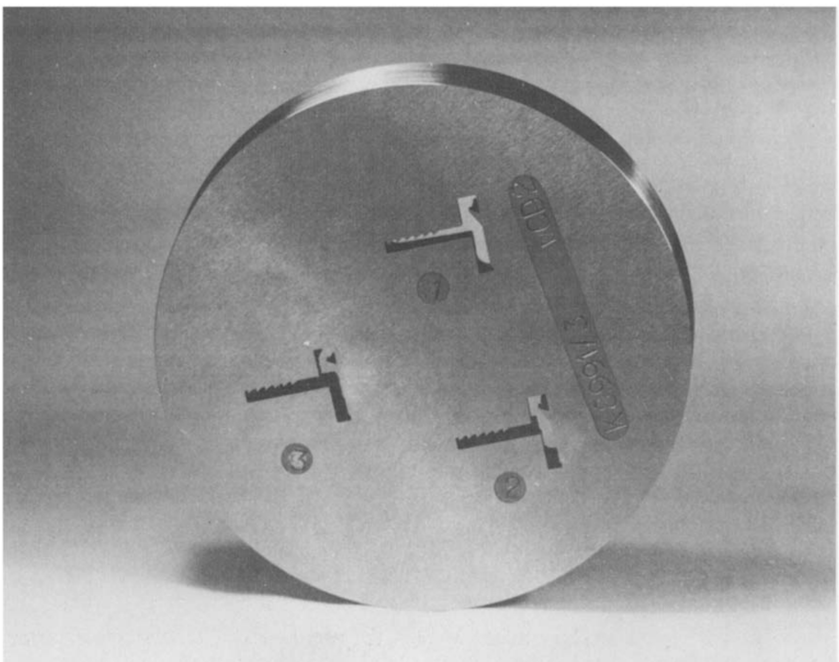
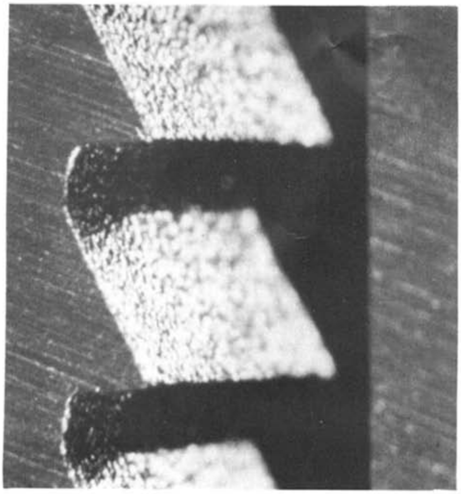


Figure 13 - Multiple passages in one workpiece can be processed simultaneously.



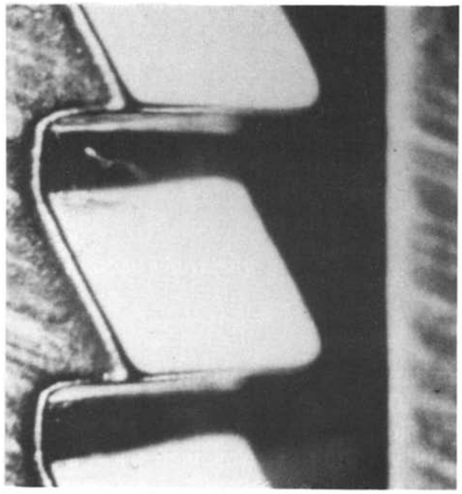


Figure 14 *Figure 15*

Close-up of the teeth on the extrusion die in Figure 13 shown before and after processing.

Whereas hand polishing smears surface peaks causing the edges to roll over and produce an inconsistent surface, the AFM process lightly grinds away the high spots of the area, yielding a more uniform, unidirectional surface and consequently a more reliable, longer lasting part. Figure 16 shows the progressive polishing action of the bearing surface on the extrusion die shown above; the processing time between each successive stage is 80 seconds.

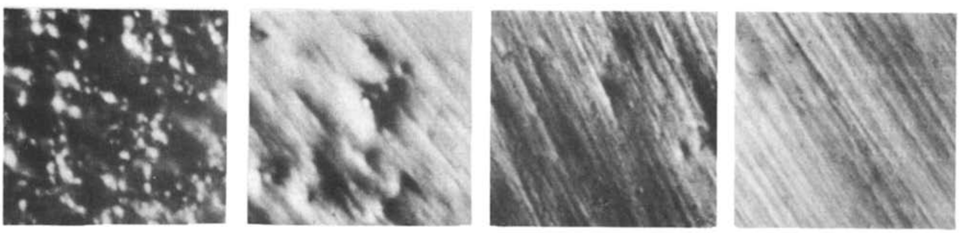


Figure 16 - Extrusion honing grinds away high spots resulting in a uniform surface.

SUMMARY

Abrasive flow machining finishes surfaces and edges by forcing a flowable abrasive media through or across the workpiece. Abrasion occurs only where the media flow is restricted; other areas remain unaffected. It can process many selected passages on a workpiece simultaneously, reaching even typically inaccessible areas. Several or dozens of parts can be processed in one fixture, yielding production rates of up to hundreds of parts per hour. A variety of finishing results can be achieved by altering the process parameters. Tooling can be designed to be changed in minutes even in production applications. The AFM process boasts reliability and accuracy, typically yielding a 90% improvement in surface finishes with stock removal controllable to within 10% of the stock removed.

The most labor intensive, uncontrollable area of production remaining in the manufacture of precision parts involves the final finish machining operations, which frequently absorb as much as 15% of the total manufacturing costs. Proper finishing of edges and surfaces affects more than the appearance or feel of a product; controlled, consistent edge and surface finishing can dramatically improve product performance and life while reducing direct labor costs. These operations have been identified as the single greatest hurdle remaining in fully automating the production of precision components. Abrasive flow machining for deburring, radiusing, sizing and polishing can be applied to an impressive range of finishing operations, providing uniform, repeatable, predictable results. With today's focus on total automation with machine tools in flexible machining systems, the AFM process offers both automation and flexibility in final machining operations as an integral part of the complete manufacturing cycle.

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