6.0 ALTERNATIVES TO CUTTING FLUIDS

In the pursuit of profit, safety, and convenience, a number of alternatives to traditional machining are currently under development. Dry machining has been around for as long as traditional machining, but has seen a recent surge in interest as more people are realizing the true cost of cutting fluid management. Minimum Quantity Lubrication is an obvious, but very intricate balance between dry machining and traditional methods. Other novel cutting fluids, such as liquid nitrogen, are also being explored for their unique properties. The following sections provide a few details about each of these technologies.

6.1 Dry Machining

Machining without the use of cutting fluids has become a popular option for eliminating the problems associated with cutting fluid management. One of the greatest obstacles to acceptance of dry machining is the false belief that cutting fluids are needed to produce a high-quality finish. Studies have shown that with proper equipment and tooling, machining without fluids can produce a high-quality finish, and be less costly than machining with fluids [26].

The advantages of fluidless cutting include cleaner parts, no waste generation, and in some cases, more precise machining [27]. In addition to these benefits, worker health concerns related to metalworking fluid exposure are eliminated. Recycling is simpler because chips generated from this technique have no residual oil on them and can be combined with other scrap metal.

These advantages do have a cost. The most prohibitive part of switching to dry machining is the large capitol expenditure required to start a dry machining operation. Machines and tools designed for cutting fluids cannot be adapted to dry cutting. New, more powerful machines must be purchased, and special tooling is often needed to withstand the very high temperature generated by dry cutting [28].

Tools are often treated with a coating that insulates the tool and the part from the heat of the cut. These tools are more expensive than traditional tools and must be replaced more often. Tool wear can increase so much that certain extreme cuts must be divided into separate processes to facilitate tool replacement [29].

Compressed air is used to remove chips that might otherwise interfere with the machining operations [28]. Dry machining leaves an unprotected surface, which on some materials may be prone to rapid oxidation (rust) [27].

The capitol expenditure required may prevent many small shops from seriously considering dry machining as an option. However, if the true cost of cutting fluid management is figured into the decision, dry machining may be a competitive or even superior investment.

6.2 Minimum Quantity Lubricant

Minimum Quantity Lubricant (MQL), also known as Near Dry Machining (NDM) or semi-dry machining, is another alternative to traditional use of cutting fluids. There are many similarities between dry machining and MQL, in fact, many research papers treat true dry machining and MQL as the same technology. As the name implies, MQL uses a very small quantity of lubricant delivered precisely to the cutting surface. Often the quantity used is so small that no lubricant is recovered from the piece. Any remaining lubricant may form a film that protects the piece from oxidation or the lubricant may vaporize completely due to the heat of the machining process.

This process, like dry machining, generates no waste cutting fluid. Small quantities of cutting fluid may need to be removed by a subsequent cleaning step. In some cases, the fluid is selected so that residual fluid does not interfere with future processing. Depending on the application, the fluid may be left on as a protective coating or anti-oxidation layer.

With the large volumes of cutting fluid used in traditional machining, misting, skin exposure, and fluid contamination are problems that must be addressed to assure minimal impact on worker health. With MQL, the problem of misting and skin exposure is greatly reduced, and fluid does not become contaminated because it is not re-used. However, fluid is still present. Proper ventilation is required to prevent buildup of vaporized fluid.

In MQL operations, fluid selection is one of the most critical decisions. The most common fluids are vegetable oil, ester oil, or a synthetic equivalent because of their superior lubrication and high-pressure performance [30]. These fluids are often much more expensive than traditional cutting fluids but, if properly selected and used, they may result in less cost per cut than the combined cost of fluid, fluid disposal, and a continuous fluid management system.

As with dry machining, special equipment and special tooling may be required. However, it may be possible to adapt some existing equipment to MQL operation. Fluid delivery is a critical operation. Cutting fluid must be delivered to the part where it is needed most. In some instances, brushing a layer of fluid over the part is sufficient. In more extreme applications, a precisely controlled stream or mist must be introduced to the cutting surface at an exact location. The degree of lubrication required and the delivery system chosen will depend on the material, the extremity of the cut, and the design of the equipment used.

While MQL may not require as large a capitol expenditure as dry machining, it is a very technical method and requires detailed knowledge of metallurgy, chemistry, and the physics of cutting in order to be implemented correctly.

6.3 Liquid Nitrogen Technology

One solution to the problem of cutting fluid management currently under development is the use of liquid nitrogen as a coolant and lubricant. This technique is not the same as cryogenic machining, where the material to be cut is cooled to a very low temperature prior to the machining operation. Rather, the method currently under development uses liquid nitrogen to perform the cooling and lubricating job of the cutting fluid. Much of the part remains at ambient temperature while the flow of nitrogen is carefully delivered to the point where it is needed. The small flow rate and low cost of liquid nitrogen make this technique a very attractive alternative [31].

This technique can be used on equipment that has been designed for use with cutting fluids, and because the nitrogen evaporates harmlessly into the air, there is no cutting fluid to dispose.

If successful, this technique will provide an alternative to businesses that want to eliminate the use of traditional cutting fluids but cannot afford the capitol expenditure required to purchase new dry-machining equipment. Reportedly, tool life and finish quality are also improved by this technique due to the low temperatures at the tool/part interface.

Liquid nitrogen is an inexpensive chemical that is environmentally inert. Nitrogen is the most abundant gas in Earths atmosphere and, when liquid nitrogen warms, it simply mixes with and diffuses harmlessly into the air. Chips generated from this technique have no residual oil on them and can be recycled as scrap metal.

Liquid nitrogen is hazardous to workers due to its extremely low temperature. Exposure can result in mild to extreme frostbite. Nitrogen that is stored in a sealed vessel will increase in pressure dramatically as it warms, potentially resulting in a non-combustion explosion. Large spills can displace all of the oxygen in a room in a short time. However, when proper equipment and handling techniques are used, nitrogen is a very safe and environmentally friendly alternative.

Creare, Inc. has developed a system intended to allow existing equipment to be modified for liquid nitrogen cooling. This system has passes phase 1 development, and is currently being developed for commercial application.

Liquid Nitrogen

Eliminating Cutting Fluids with an Affordable Machine Tool Cooling System

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At Creare, we have developed a novel technology that eliminates the use of machining cutting fluids by indirectly cooling the cutting tool. Our innovation is a prevention-oriented solution to the environmental and occupational health problems posed by cutting fluids that can be easily integrated with existing machine tools. Our proof-of-concept research has clearly demonstrated the technical and economic feasibility of our proprietary cutting tool cooling system. When compared to dry cutting and jet cooling with a synthetic coolant, we demonstrated that our tool cooling technology: (1) reduces the environmental cost of the machining process by 200% for jet cooling with a synthetic coolant and by 21% for dry machining, (2) increases the tool life by 700% at low-cutting speeds and by 50% at high-cutting speeds, (3) decreases part production costs by at least 20%, and (4) improves the final part quality while maintaining a high degree of dimensional accuracy (Rozzi and Elkouh, 2002).

Cutting fluids have long been used in machining processes to decease the temperature during machining by spraying the coolant into the machining zone directly on the cutting tool and the part. This has the effect of decreasing the tool temperature, which increases tool life and improves the part quality. However, cutting fluids are environmentally unfriendly, costly, and potentially toxic (Sutherland, 2000). The recent shift to dry cutting has not completely solved the problem. Dry cutting increases energy costs, increases per part costs, and requires a capital investment that is too large for most machine shops. New alternatives to traditional flood or jet cooling include mist cooling with natural oil, through-tool delivery of traditional machining coolants, high-flow cryogenic cooling (Hong and Ding, 2001; Wang and Rajurkar, 2000; Zhao and Hong, 1992), and high-pressure water jet cooling (Kaminski and Alvelid, 2000; López de Lacalle, et al., 2000). None of these approaches is a cost-effective or practical way to eliminate the use of environmentally unfriendly cutting fluids. They either require oils of questionable effectiveness or high-flow, high-pressure systems that would be costly and difficult to implement in a production environment

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Creare plans to continue research and development of this exciting new technology. Our continued research will focus on in-plant testing, integration, design for manufacture, and commercialization of our environmentally-conscious machining system. In addition, we are investigating the application of the technology to the machining of advanced materials, ultra-accurate machining, and vision-based control of machining.

Biography:
Dr. Jay C. Rozzi received undergraduate, master's, and Ph.D. degrees in Mechanical Engineering from Purdue University. He has studied materials processing and non-traditional machining for nearly a decade. Dr. Rozzi's general areas of interest are heat transfer, materials processing, materials science, aerodynamic heating, two-phase flow, and cryogenics. While at Creare, Dr. Rozzi has led or executed projects including aircraft fuel-tank inerting systems, novel corrosion-resistant blankets, the laser annealing of plasma-sprayed ceramic coatings, environmentally-conscious machining, and high-efficiency paper drying.

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Liquid Nitrogen