



Internal cooling channels: Challenges, potential for gear applications

Internal cooling channels have shown great promise in improving the performance of components such as injection molds and rocket engines. These conformal cooling channels have been hypothesized as value-adding enhancements to gear systems. But challenges remain to further consider and actualize these concepts.

One of the best-use-cases of powder bed fusion (PBF) additive manufacturing (AM) is for the fabrication of internal channels, especially complex ones. Rocket engines and molds are two component types that have taken advantage of this capability.

In the case of rocket engines, cooling channels would otherwise be fabricated via dozens, if not hundreds, of brazing steps — each one having the potential to scrap the entire component. For molds, brazing could be used or other traditional methods such as drilling could be employed, but your design would be restricted in its complexity and would likely result in less effective cooling/heat transfer (see Figure 1). Thus, AM has shown excellent capability to improve component performance and/or simplify manufacturing processes by reducing operation steps for components that require cooling channels. However, PBF AM surfaces are granular with high levels of roughness and waviness (see Figure 2). These surfaces have the benefit (for heat transfer) of having very high levels of surface area, but, for flow-based systems, these surfaces cause significant pressure drop and can result in issues such as inadequate flow (which in turn hinders effective heat exchange).

While not as obvious of an application for internal/conformal cooling channels as rocket engines or molds, gears are nonetheless an interesting application to consider. The potential to control and/or reduce the operating temperature of gears could provide significant system benefits. Perhaps the most logical benefit that conformal cooling channels (CCC) within a gear system could provide may be relative to scuffing. “Scuffing is the sudden failure of the lubricant layer during operating conditions, normally occurring under high load or high speed.” [2] Scuffing is strongly linked to operating temperature as increases to lubricant temperature are known to reduce lubricant film thickness, increasing the risk of scuffing.

Reductions in surface roughness, especially via isotropic superfinishing processes, have been shown to significantly increase scuffing resistance both due to the increases to the operating lubricant film thickness and due to the reduction to gear system friction (and the associated heat generation) [1]. Thus, reducing the rise in operating temperature of a gear system will reduce the risk of scuffing.

AM CCCs in molds have shown significant improvements in cooling time as compared to traditional mold cooling channels (TMCCs). However, as expected, these AM CCCs exhibit much higher pressure drop than TMCCs. Flow rate increases are required to improve temperature uniformity and maximize the efficacy of the AM CCCs [1]. When applied to gears, AM CCCs have the potential to achieve similar improvements relative to component cooling and derivatively operating temperature (see Figure 3 for an example of gear CCCs).

One study found that AM CCCs could increase the resistance to scuffing by ~30% versus traditional gears [3]. Returning to the issues

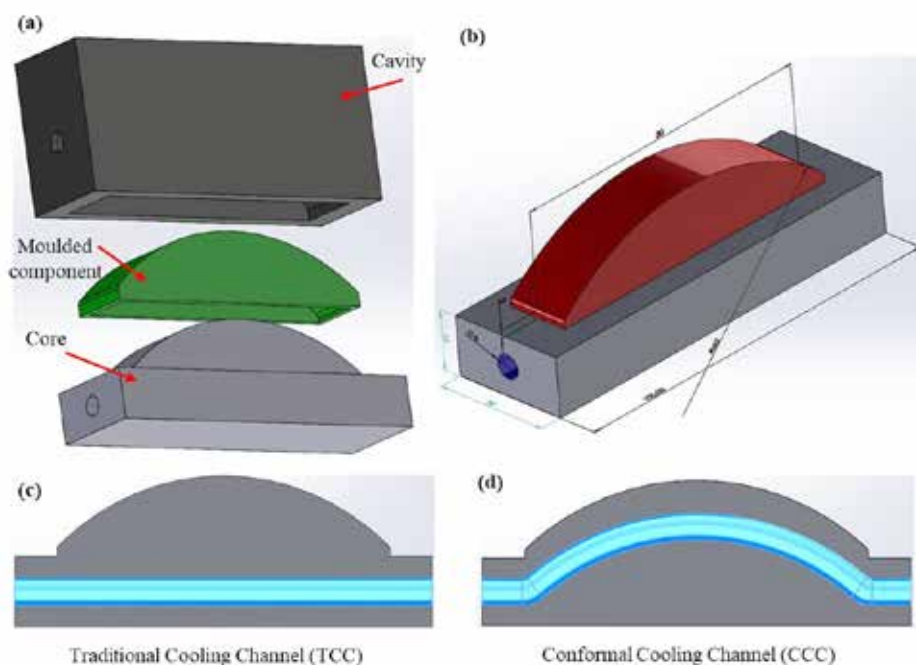


Figure 1: Example of Traditional vs. Conformal Cooling Channels in a Mold Core. [1]

caused in mold cores by the AM surface texture within CCCs relative to temperature uniformity, one must be concerned about the effect of this temperature non-uniformity on gear dimensions as dimensional stability within molds is known to suffer under these conditions [4]. As scuffing has been hypothesized to be linked, in part, to gear swelling due to increased operating temperature, the use of AM CCCs in gears must take into account and/or address the potential challenges linked to high levels of internal surface roughness leading to flow and temperature irregularities and the potential dimensional variations these temperature irregularities may cause.

Pressure losses within the channels can be overcome by higher flow rates, but high flow rates may require stronger (larger/heavier) pumps. As scuffing is commonly a concern for aerospace gearing (which operate under high speed and high load regimes), the addition of weight to any system is problematic. Thus, minimizing pressure losses to AM CCCs within gears is of paramount importance for this concept to have viability.

However, the challenges linked to fabricating CCCs without AM can be closely equated to the challenges of improving the surface roughness of AM internal channels. These CCCs, by nature, lack line-of-sight access and are commonly very small, in some cases <1 mm. Thus, no traditional machining operations can be considered to improve these surfaces and reduce their pressure losses. Concepts with questionable efficacy and applicability to non-straight channels such as flexible rotary tools have been proposed, but no evidence of these experimental processes being effectively applied to serpentine channels exists (so they should be ignored at this time). Electrochemical processes cannot be easily applied as any wall contact will render the process ineffective. Thus, only spontaneous chemical processes or abrasive putty-based processes can viably be considered to address the challenges of AM internal channels.

These processes both have their strengths and weakness, and these strengths and weaknesses must be considered before one can be selected. A future column will review these processes for internal channel surface finishing applications.

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Figure 2: PBF-LB/Ti-6Al-4V surface showing high levels of texture and granularity (Courtesy: REM Surface Engineering)

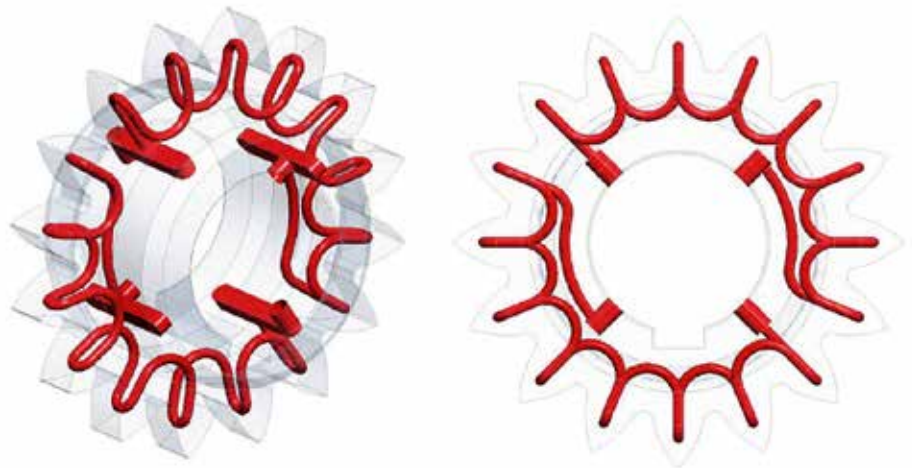


Figure 3: Conformal Cooling Channels in a Spur Gear. [3]

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Justin Michaud is president and CEO of REM Surface Engineering where he works closely with the Research Team, supports REM's government projects and awards, and focuses heavily on REM's surface finishing solutions for metal additive manufacturing applications. Michaud serves on the AGMA Emerging Technology Committee where he is the former chair of the 3D Printing sub-committee. He is also a member of the AGMA Board of Directors. Michaud is an author of multiple technical papers on topics including additive manufacturing for space and defense applications, isotropic superfinishing, gear failure modes, surface texture and measurement, high-value gear repair, and the superfinishing of high-hardness steels. Michaud has overseen the successful execution of multiple NASA, Air Force, and DOE SBIR programs.