Tooling around with moly

Metalworking tools must survive high temperatures, extreme stresses, friction and wear, and still economically produce precision parts from difficult-to-process alloys. In some applications, traditional steel and nickel-alloy tools cannot do the job. Molybdenum metal alloys like TZM and MHC solve this problem, saving material and processing costs, and enabling new and better technologies.

Hot metalworking machines apply thousands of tonnes of force to shape large workpieces. They require dies and tooling made from special alloys that must retain their strength at temperature and resist erosion by the workpiece. Molybdenum has been an important component of tool steels for about a century because it improves hardenability and high-temperature strength. New workpiece alloys capable of higher temperature operation required both higher processing temperatures and improved tooling materials. Eventually, tool steels, nickel alloys, and cobalt alloys were found wanting for some special applications. These applications now use molybdenum where tool temperature can exceed 1100°C. The two examples discussed in this article vary greatly in size, with one using tools weighing only kilograms, the other weighing several tonnes.

The extrusion press – a high-temperature, high-pressure toothpaste tube

The extrusion process is analogous to using a toothpaste tube. Squeeze the tube and out comes a small cylinder of toothpaste. An extrusion press does the same thing, but with a solid metal workpiece called a billet. In hot extrusion, the billet is softer than it is at room temperature, but it still retains significant strength. The press holds the billet in its heat-resistant steel container, and its ram pushes the billet through a die to make a long bar in the shape of the die's opening.

Brass extrusions start with a typical two to three meter-long cast ingot having a diameter of about 250 mm. The 'extrusion constant,' the ingot cross-sectional area divided by the extrusion cross-sectional area, influences the force required to extrude the ingot. The constant of some brass extrusions can be as high as 1600*, demanding high forces and large deformations. Even with pre-heating to 600–1100°C, depending on the alloy, 3,000–4,000 tonnes of force are needed to extrude an ingot of this size.

The process creates high stresses in the die and large amounts of die to workpiece friction. The deformation and friction also create heat that reduces the die material's strength and increases thermal stresses in the die, further challenging the tooling. Production campaigns process many ingots, so dies must also resist fatigue and creep. Die cracks associated with fatigue or overloading create fins in the extrusion that require expensive hand finishing. Dies must resist all these phenomena to make high-quality finished products.

The molybdenum MHC alloy with approx. 1.2 wt. % Hf and 0.08 wt. % C, solves these problems. MHC is nearly 99% molybdenum, so has excellent thermal conductivity and low thermal expansion, both of which reduce thermal stresses. MHC has significantly better

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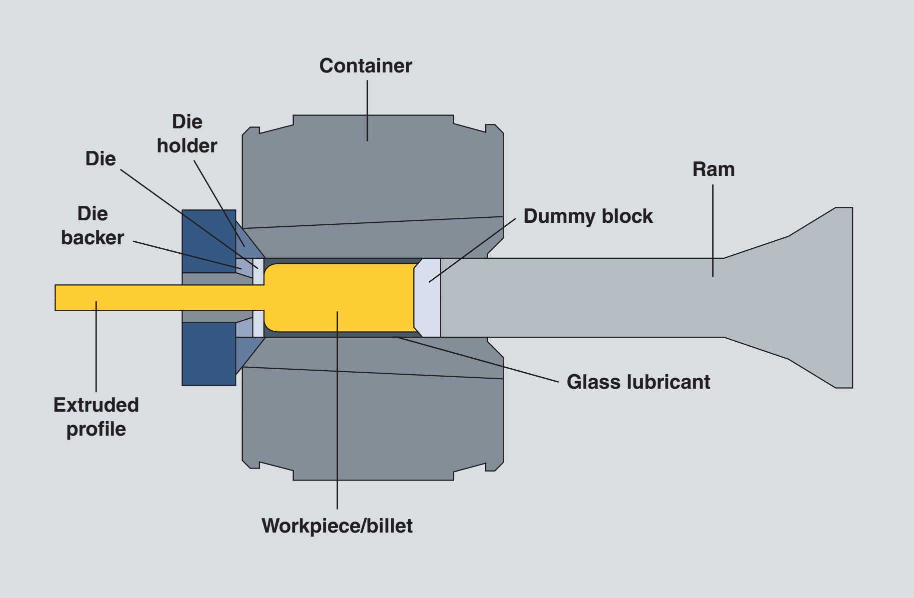

Schematic drawing of an extrusion press.

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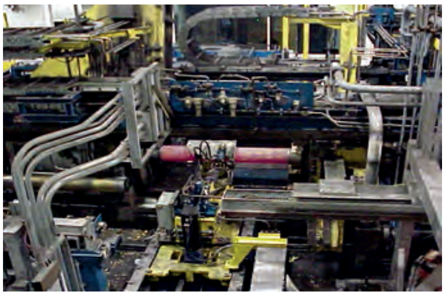
* The cross-sectional area of the billet is 1600 times larger than that of the extrusion. For this extrusion ratio, a 250-mm diameter billet would produce a round bar having a diameter of 6.25 mm.

Bundles of finished brass bars. © Chase Brass and Copper Co. LLC



Copper alloy billet in position for extrusion.
© Chase Brass and Copper Co. LLC

strength at extrusion temperatures than standard hot-work tool materials. It resists erosion, extends die life and improves the product's dimensional uniformity. MHC dies have up to ten times the life of dies made from Rexalloy®TM, a competitive extrusion-die alloy. Brass extruders consistently choose MHC over other die materials for these reasons.

Isothermal forging – making waffles with a 40,000-tonne press

Gas-turbine efficiency depends directly on operating temperature. Over many years of engine development, operating temperatures were continuously pushed higher, requiring new materials with ever better high-temperature performance. Because these materials had such high strength at elevated temperatures, the traditional tools to shape and form them were no longer adequate. One such part that threatened to stall progress of turbine efficiency was the turbine disk (see insert p. 10). Only when engineers found a new way to forge IN-100, a heat resistant cast alloy that was not forgeable with traditional methods, could they advance the technology.

A way to forge 'unforgeable' alloys

The key to success was to start with a very fine-grained input material and to 'superplastically' forge it at very slow speeds. This required both the tool and the workpiece to be heated to the forging temperature (1100–1200°C) for long periods while in contact with one another in a protective-atmosphere chamber. Although the disk alloy did not flow quite like wafflebatter at these temperatures, it still moved freely, filling out the die and creating much finer detail than was previously possible. The protective atmosphere minimized scaling of the expensive superalloy, further reducing cost and improving quality.

Finding an appropriate die material was a unique and daunting challenge because no traditional tooling material could survive the process. Enter molybdenum TZM alloy with approx. 0.5 wt. % Ti, 0.08 wt. % Zr and 0.03 wt. % C. Despite its tiny alloy content, TZM has extraordinary strength at the isothermal-forging temperature, so it was perfect for the dies.

Making TZM dies

Today's large TZM die blanks, which can weigh as much as 5,000 kg and measure a meter in diameter and height, are made by standard powder-metallurgy techniques applied on a grand scale. The blank must be forged on a 30–40,000 tonne press (more than enough force to lift a battleship!) at temperatures approaching 1200°C, in order to increase its strength to tackle the job. Installed in its own forging press, a finished pair of dies must produce hundreds of flawless nickel-base superalloy disks that help modern jet engines to fly safely, economically, and with minimal environmental impact.

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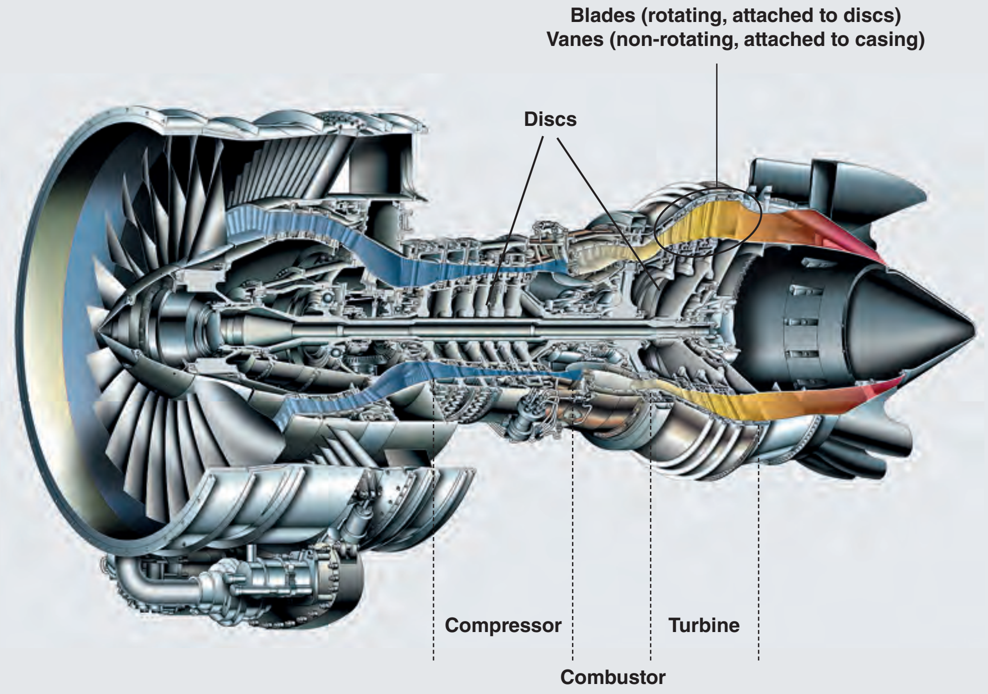
Development of gas turbine engines

Axial-flow turbine engines used in today's aircraft are marvels of design, materials, and manufacturing. They have a compressor section that creates high-pressure air and injects it into a combustor where it burns the engine's fuel. The high-pressure flame enters the turbine's hot section and drives the turbine shaft, then enters the exhaust cone where it expands and propels the aircraft.

In order to maximize power and efficiency while minimizing environmental impact, jet engines must operate at the highest possible temperature. Flame temperatures in today's engines exceed the melting point of the engine's hot-section turbine blades. Only by employing superb mechanical design, unique materials, sophisticated coating technologies, and exceptional manufacturing techniques are manufacturers able to produce turbine blades able to operate in this environment.

A sampling of nickel-based superalloys for jet-engine turbine disks

Alloy	Developer	Decade	Base alloy	Nominal Mo, weight-%
Waspaloy®	United Technologies	1950 – 1960	Ni-Cr-Co	4.3
IN-100	INCO	1960 – 1970	Ni-Co-Cr	3.0
Udimet® 720	Special Metals	1970 – 1980	Ni-Cr-Co	5.0
René™ 95	General Electric	1980 – 1990	Ni-Cr-Co	3.5
N18®	SNECMA	1990 – 2000	Ni-Cr-Co	7.0
Alloy 10	Honeywell	2000 – 2010	Ni-Co-Cr	2.7



Cutaway drawing of a Pratt & Whitney PW6000 jet engine, showing compressor, combustor, and high-temperature turbine stages. Each stage has rotating disks to which blades are attached. Between the bladed disks are stationary vanes, attached to the turbine case. © 2014 United Technologies Corporation – Pratt & Whitney Division

The turbine disk – holding it together

Turbine disks hold the spinning blades that compress air and extract power from the heated gas. They must endure high stresses, and in the case of hot-section disks, high operating temperatures also. Many disk alloys contain molybdenum because it contributes to high-temperature strength and creep resistance. Until the 1960s, disks were manufactured by standard forging practices; disk alloys could not supply the high-temperature performance of cast blade alloys, which were unforgeable. Steady increases in engine performance eventually pushed hot-section forged disk alloys to their temperature limits, stalling progress.

In a major step forward, Pratt & Whitney engineers devised a unique isothermal forging process to manufacture disk preforms from IN-100, a previously 'unforgeable' blade alloy. The process made forgings about 30% lighter than conventionally forged disks with dimensions much closer to those of the final part, which dramatically reduced input material costs, scrap rates, and machining costs.

The world aircraft market continues to grow, and demands for ever-higher engine operating temperatures continue to spur a need for forged superalloy disks in more locations in the engines. Molybdenum will continue to play an important behind-the-scenes role in manufacturing these remarkable power plants.

Molybdenum: an extreme solution

Hot metalworking processes are indeed extreme; they make extraordinary demands on tooling. Molybdenum has long been an important component of traditional tool alloys, but it becomes itself the tool alloy when nothing else works. Whether for relatively small dies used in brass extrusion or for isothermal-forging dies weighing thousands of kilograms, molybdenum metal alloys make advancements in hot metalworking possible. (JS)

Isothermally forged superalloy disk being ejected from Mo-TZM die after forging. © ATI Forged Products