

ASK THE EXPERTS

This section gives readers the opportunity to ask questions on issues they may have in their day-to-day operations or general problems with a die casting process. Our team of experts ranges from scientists to consultants, professors to CEOs. These individuals take time to respond to questions relating to Die Casting Engineer's themes, drawing from their knowledge and experience within the industry.

What materials and/or processes are available for me to improve die life?

A: This question begs for more information. The first differentiation is the type of die casting we are referring to.

In the case of zinc die casting, cold chamber, start with a Premium H13, which gives a good combination of hardness and toughness. If wear is an issue, then new hot work grades with the ability to obtain hardnesses of up to 58 HRC are recommended. Call your tool steel provider to determine what grades they carry that meet this criteria. Grades like M2, M3:2 and M4 powder metallurgical grades, and T15 alloys can also be used, although the difficulty in welding those alloys will increase over the hot work tool steel types.

In the case of aluminum die casting, start with a Premium H13, and then move to the new higher ductility hot work tool steels currently on the market that minimize heat checking and gross cracking. If erosion is the major issue, then coatings may be a necessity. Localized additions of ferritic nitrocarburizing or nitriding, or overall deposits of physical vapor deposition (PVD) of Ti_3AlN , TiN , or $TiCN$ coatings can be entertained, or a combination of both. Currently, NADCA is evaluating multilayer coatings of PVD to recommend the best series of coatings for these applications.

To give a better answer to this question, please tell us the type of die casting, the alloy type to be cast, the shot size, heavy wall

or thin wall casting, the failure mechanism you think is taking place, and the current material and hardness in use. Also, if you have any interesting design or production issues this will help determine the best material and/or coating combination.

*Member of NADCA's
Die Materials Committee*

A: Die life is determined by many factors, including die design, selection of the die material, fabrication methods, operating conditions and maintenance. H13 is still the most popular die material used by die casters in the U.S. It is available in Standard, Premium and Superior grades. The Premium and Superior grades are usually made by vacuum Arc Remelting (VAR) or Electro-Slag Remelting (ESR) of the standard H13. These processes produce superior steel with low sulfur, phosphorous and inclusion content as well as a tightly controlled carbide size and distribution. The NADCA 207-2003 Specification for Premium Grade H13 provides detailed guidelines and acceptance criteria for these materials. Compliance with the specification ensures a sound die material and guarantees a minimum of 8 ft. lb. for the Premium grade and 10 ft. lb. Charpy V-notch impact value for the Superior grade. In recent years, new die materials have become available that often exceed the performance of H13. These are modified versions of H11, a tool steel frequently used



A: Obviously, the premium grade H13 is the best way to start, but one must ensure that it has had the proper heat treatment. Short cuts during construction can reduce the effectiveness of the material. But, the biggest thing one can do is to keep the die hot. Cold dies tear up the die steels, and all too often dies are over cooled with die spray and/or slow cycle rates.

— NADCA Instructor

A: At present time, the developments have indicated that a modified H11, when heat treated properly to provide a hardness level of 48 HRC is the best material to use to improve die life. This includes a cooling rate of about 200°F/Min. in the critical range and heat treating by at least double temper to 48 HRC. The cooling of the die surface should be with water or possibly hot oil to keep the surface of the die at low temperature.

— NADCA Honorary Member

in Europe. The higher molybdenum with lower silicon and vanadium of these steels provide higher toughness than H13 with good temper resistance that extends die life in demanding die casting applications.

A critical process in extending die life is the heat treatment. Dies are usually quenched with nitrogen in a vacuum furnace. A high cooling rate during quenching is essential to ensure long die life. The current NADCA specification requires a minimum of 50°F/min cooling rate, as measured by a thermocouple inserted in the die. Reputable heat treaters use six or ten bar nitrogen quench furnaces to attain these high cooling rates. To avoid quench cracks in large dies, it is common practice to interrupt the quench. This allows the inside temperature to equalize with the surface temperature thus minimizing thermal stresses and distortion of the die. Some distortion is however inevitable and is actually a good indicator of a fast cooling rate. Extra stock material should therefore be allowed to permit finishing the die to the required tolerances. The quench is followed by a double temper of the insert. Hardness levels up to 48-49 HRC can be used for smaller inserts. The higher hardness level will improve the thermal fatigue resistance of the steel, extending die life. However, high hardness can also lower the toughness of the steel. Large dies are therefore tempered to 44-46 HRC or less, to reduce the danger of gross-cracking. Often times Electro-Discharge Machining (EDM) with graphite electrodes is used to create the final details in the cavity. The EDM process leaves a thin "white layer" on the surface of the insert. This thin layer is formed by re-solidification of metal molten by the EDM current. Use of low power during the final stages of the EDM and polishing of the surface to remove the white layer and machining marks can contribute to

extending die life.

Generally, die steels provide a satisfactory performance at competitive material and fabrication cost. In certain situations, such as hot spots in the die, excessive soldering and/or washout, alternative materials, surface treatments or coatings should be considered. Refractory alloys such as the tungsten-based Anviloy 1150 have outstanding thermal fatigue and soldering resistance and make superior cores and core pins. However, these materials are more expensive and difficult to machine than steel. The pros and cons of using them have to be considered on a case by case basis.

— *Researcher/Author of more than 100 papers/publications*

A: The degradation of dies and the limitation on die life is caused mainly by three degradation mechanisms:

- (i) Soldering and chemical attack between the liquid metal and the die material — typically H13 tool steel, although alternative materials are now being examined such as Anviloy — a tungsten alloy
- (ii) Wear and erosion
- (iii) Heat checking or thermal fatigue cracking due to the thermal cycling that takes place with each shot cycle

Let me deal with each one of the above three failure mechanisms, one at a time starting with (iii).

Professors at the Case Western Reserve University in Cleveland have worked for many years on improving the resistance to thermal fatigue cracking of tool steels. The person asking the question should consult these people on this topic and look at the papers that have been published through NADCA and other sources over the past 20-30 years.

Possibly the most important failure mechanism in dies used in pressure die casting is (i): the soldering and chemical attack

that takes place between the die tool steel and the liquid metal, e.g., Al. Several surface modification techniques such as ferritic nitrocarburizing and plasma ion nitriding can and are being used extensively to improve the die life over non surface modified tool steel dies. These surface modifications can also improve the wear and erosion resistance of the die surface. But the improvement is limited to a small amount in most cases.

The best method to extend the die life with respect to this problem of soldering and chemical attack is to use non wetting, hard coatings on the die surface. The hard coating must be non wetting (or as non wetting as possible) with the liquid metal (Al), and sufficiently hard to minimize erosive wear of the surface. At the same time, there is some advantage in depositing the coating as multi-layer and/or graded system. At the Colorado School of Mines, they have developed a specific design methodology for die coatings that generates a multi-layer/graded coating system comprised of:

- (i) a working layer that is non wetting with the liquid metal. In this respect Cr-N, Ti-Al-N, Ti-C-B, Al₂O₃ working layers are relatively non wetting with Al
- (ii) an intermediate graded layer that accommodates the thermal residual stresses that are generated in the shot process cycle. This will depend on the working layer selected, for instance a graded Ti-Al-N intermediate layer works well for the Al₂O₃ working layer
- (iii) an adhesion layer that improves the adhesion of the coating to the H13 tool steel
- (iv) Surface modification of the H13 tool steel using ferritic nitrocarburizing or plasma ion nitriding.

The overall thickness of the total coating system is between 5 to 8 micrometers (Microns), and can be deposited onto the surface of the H13 tool steel using most physical vapor deposition (PVD) techniques. The researchers use closed field unbalanced magnetron sputtering, because they feel that this is the most versatile PVD technique.

The PVD coating needs to be relatively tough since any fracture or crack in the coating will cause the underlying H13 tool steel to be chemically attacked by the liquid Al as is the case with uncoated H13. At the same time, the presence of the coating does not greatly decrease the thermal fatigue problem. This is best addressed from using the best alloy and heat treatment. Nevertheless there is some indication that coatings can to some extent delay thermal fatigue cracking. One other important point is that once coatings are used on the die, die cleaning practice must change. You can no longer use abrasive stones to clean the die surface since these will degrade the coating. Instead, the die can be cleaned using a paint brush dipped in dilute caustic soda solution to remove any excess aluminum for instance.

There are sufficient data to indicate that the application of these coating systems can improve die life from 4 to 15 times depending on the casting process parameters, and alloy being used.

— *Head of a university metallurgical department*

A: The common term “die life” while not misused, it is often misunderstood and might be better called die performance. Die performance however may mean different things to different organizations because of the way it is or is not measured. Nevertheless, the one thing that everyone

may agree on is that improved die life or die performance means more parts at less cost. Therefore, die life is often considered second only to cycle rate as the holy grail of profitable die casting.

Die life comes in 1 primary measurable input and 2 resultant output categories.

Input: Total amortized die cost -
New die cost + aggregate repair cost before retirement.

Outputs: Uptime – The number of shots between in-machine die-related repair events.

Repair/Downtime: Die repair hours between casting production runs.

Improved die materials continue to offer incremental and in certain cases, more dramatic improvement in the total shot counts possible before die uptime, die repair/downtime, and casting quality or die-limited productivity reach unacceptable levels. Improved heat treatment processes contribute to improved die life in all measurable categories. Coatings and surface treatments are more widely accepted and available because of the increasing die life benefits possible. Improvements in this field known as die surface engineering leverage the die material or substrate improvements available. While such surface engineering enhancements often provide increased die life, the downstream benefits of increased uptime and reduced casting scrap can be even more significant. The common thread however, is consistent measurement and control through technical understanding and execution through procedural discipline.

Because many, many die materials, heat treatment, and surface engineering alternatives are available, a nearly infinite number of combinations also exist. Emerging technologies which limit the

pressure impact spike at the end of cavity fill can also have a significant effect on die life in ways other than through reduced soldering, erosion, heat-checking/thermal fatigue and surface lube effects, the primary die failure mechanisms and cost drivers. The challenge therefore is to find the best compromise if not the optimum material and process combination for each particular economic case because no one single material or process solution can meet the diverse demands of the die casting industry. One fact is clear however. General improvement in die materials, surface, and process engineering science is driving overall die life improvement helping to keep North American die casters competitive.

My best recommendation is to talk to your die material, heat treatment, and die surface engineering suppliers, but first, participate in and contribute to the NADCA-led die materials and surface engineering effort. The collaboration among industry and research professionals is driving improvements to new heights with each succeeding year. Improvements can only be fully leveraged however, if the fundamentals are understood and the alternatives are known. Regardless of the die material, process, and surface engineering technology employed, improved die life can only be quantified, and the resultant benefits accrued only if the elements which determine die performance are measured and controlled as inputs and are continuously compared with the resultant outputs over time.

— *Chief Engineer*

*Have a question you need answered now? Try visiting NADCA's Technical Forum, a place where you can interact with your die casting peers and share ideas, experiences and information:
www.diecasting.org/technical*