WHITE PAPER

Technologies and Strategies for Longer Lasting Die Casting Dies

NADCA

North American Die Casting Association

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This paper focuses on technologies that can enhance the life of die casting dies and is complimentary to the previously publish white paper entitled "Five Steps to Improving Die Performance". In order to extend die life, it is important to know what is limiting the life of dies so the appropriate technology can be utilized. For years the reasons for retiring a die from service have remained the same. The top reason for dies being retired from service prematurely is thermal fatigue cracking and this has not changed over the years. After thermal fatigue, the primary reasons for retiring a die are: gross cracking, wear and erosion (washout), cavitation, and chemical attack. What has changed over the years is a great reduction in, and near elimination of, the instances of gross cracking. This is primarily due to the increase in the minimum acceptable impact strength (toughness) of the die steel and several new die steels that have the capability of yielding impact strength levels well beyond the minimum requirements of the NADCA Special Quality Steel and Heat Treatment Acceptance Criteria for Die Casting Dies document.

Key technologies that can be utilized to address the reasons dies are retired, and hence, extend the life of dies are:

1. New die steel compositions
2. High thermal conductivity materials and bi-metallic die components
3. Improved cooling line placement
4. Cooling line control
5. Advanced coatings and surface treatments

Since thermal fatigue is considered to be the top die life limiting factor, technologies that assist in reducing the onset of thermal fatigue cracking, either by enhancing the thermal fatigue resistance of the die material or by reducing the differential in temperature the die experiences, will be presented first. Then technologies to combat wear, erosion, cavitation, soldering and chemical attack will be presented.

New Die Steels

Much research and development has been conducted on H13 die steel chemistry and heat treatment to improve its impact toughness and thermal fatigue strength. Through this work Superior Grade H13, a more resilient grade compared to Premium Grade H13, was defined. In addition, several other steel compositions with improved impact and thermal fatigue strength over Premium Grade H13 have been developed and added to the Special Quality Steel and Heat Treatment Acceptance Criteria for Die Casting Dies document under various classifications defined as Grades A through F. Average impact strength capabilities, as high as 20 ft-lb, are specified for these newer steels, as compared to 8 ft-lb for Premium Grade H13. Data from the industry indicates that dies with an impact strength at or above 10 ft-lb are not prone to gross cracking. In addition, thermal fatigue testing has shown substantially higher thermal fatigue strength for the newer steels as compared to Premium Grade H13.

Therefore, opportunities for longer die life exist where gross cracking or thermal fatigue is the reason for die retirement, through the use of newer die steels.

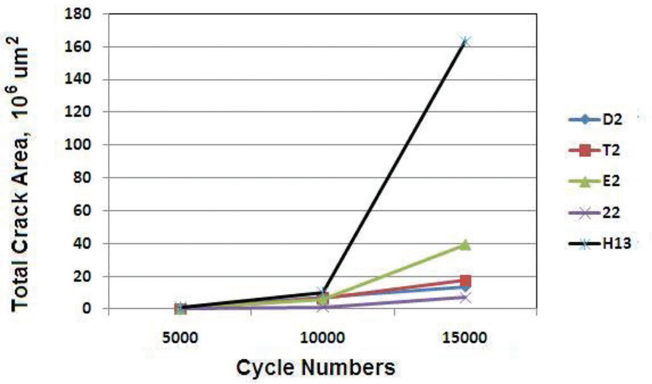

Figure 1 – Results of laboratory thermal fatigue tests of four newer die steels as compared to H13.

Thermal fatigue results of four newer die steels as compared to H13 at hardness levels of 44-46 HRC are presented in the figure. The lower the curve the better the resistance to thermal fatigue cracking. A substantial improvement is shown for the new steels.

High Thermal Conductivity Materials and Bi-Metallic Tooling

Hot spots on die cavity surfaces reduce die life. Softening of the die steel occurs when temperatures above the tempering temperature (typically 1050-1100°F) are experienced by the die component for extended periods of time. This is a temperature and time related phenomenon. The higher the temperature, the shorter the time, and the longer the time, the lower the temperature required to soften the die steel surface. Once the die steel surface has softened to approximately 38 HRC from its initial hardness (typically 44-46 HRC), it loses thermal fatigue strength and becomes more prone to thermal fatigue cracking/heat checking. Therefore, the onset of thermal fatigue cracking can be delayed by drawing the heat out of the die component more quickly so softening of the surface is delayed or eliminated.

One method for drawing heat out in local areas of the die more quickly is to replace the die steel in the hot areas with a material that has higher thermal conductivity than the typical die steel. Anvilloy, a tungsten-base alloy is one such material. TZM, a molybdenum-base alloy is another such material. Although these two materials have been available and used for years, their use is not as prevalent as the needs suggest.

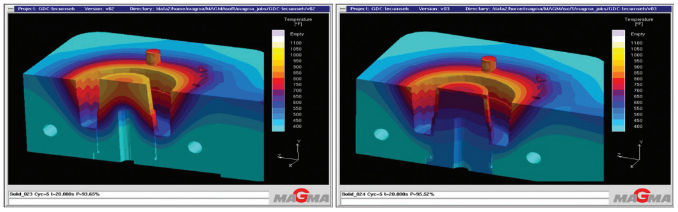

Figure 2 – *Screen captures from a computer simulation showing that the hot spot in a core (left) fabricated from H13 is reduced by approximately 100°F when fabricated as a bi-metallic core (right).*

Figure 3 – *Schematic of the bi-metallic core. The yellow represents copper and the green represents H13.*

Much more recent the bi-metallic tooling technology has been demonstrated. Bi-metallic tooling, as the name implies, is composed of two different metals – die steel and copper. Copper has excellent thermal conductivity and is what is used to draw heat out of the bi-metallic die component quickly. However, copper dissolves in molten aluminum, so it is coated with a layer of die steel which acts the working layer and barrier between the incoming molten metal and the copper. The die component is cut about 0.10 inch per side undersize in copper, then coated with die steel, such as H13, by the direct metal deposition method, and lastly finish machined to final dimensions. In-plant trials have shown cores produced of bi-metallic material to reduce hot spots by 100°F and increase the life of cores.

Added benefits of reducing hot spots are shorter cycle time, if the hot spots are a limiting factor for ejection, and minimization or elimination of solder which causes downtime and casting non-compliance issues.

Cooling Line Placement

Typically, cooling lines are placed no closer than ¾ inch from the die cavity surface. This is to minimize the risk of cracking that can cause a path from the cooling line surface to the cavity surface. But this typical placement has been set based on the properties of Premium Grade H13. With the advent of newer die steels with higher impact and thermal fatigue properties, the risk of cracking is reduced, allowing cooling lines to be placed closer to the cavity.

In-plant trials have been conducted on a newer die steel with cooling lines placed ½ inch from the cavity surface. As compared to Premium Grade H13 with cooling lines placed at ¾ inch from the cavity surface, the new steel with closer cooling line placement yielded a 30% longer life while reducing casting cycle time by 12%. Clearly placing the cooling line closer to the surface will increase the heat removal and reduce the cycle time. What is less clear is the reason for improved die life. It is theorized that the narrower temperature cycle from the improved heat removal results in lower thermal fatigue stress as well as reduced softening of the cavity surface, thereby, extending the thermal fatigue life of die components.

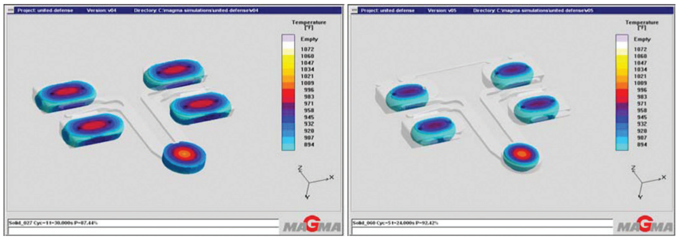

Figure 4 – *Screen captures from a computer simulation to illustrate that the shot is cooler (right) at the same point in time in the process cycle when cooling lines are closer to the cavity surface.*

Cooling Line Control

Figure 5 – *Photograph of a DTE cooling line water control system.*

Internal cooling lines need to be controlled so that excursions in temperature that shock the die and increase the thermal fatigue stress are eliminated. By eliminating these temperature excursions which reduce die life, die life can be preserved or extended. At a bare minimum, the flow rate of the cooling media is to be measured with flow meters and controlled. Beyond typical flow meters, there is a new system that controls water flow rate on a shot by shot basis based on computer calculation of the actual heat being removed. A computer controls fast acting valves to adjust water flow and prevent temperature excursions. This type of new control system (produced by Die Therm Engineering) monitors and controls the actual internal heat removal of the die. Therefore, die temperatures remain very consistent resulting in extended die life. Added benefits include consistent product quality, reduced cycle time and less downtime.

Coatings and Surface Treatments

Several coatings and surface treatment are available. Thermal diffusion coatings, precision shot peening, electroplatings, PVD and CVD coatings have been used over the years with varying degrees of success in reducing wear, erosion, cavitation, soldering and chemical attack. Shot peening and multi-layer coatings can also assist in reducing the onset of thermal fatigue cracking. The most recent technology is the multi-layer coating technology which provides an outer working layer that is resistant to wear, erosion, cavitation, soldering and chemical attack and under-layers that manage stress from die surface to the outer working layer which provides for some thermal fatigue resistance. Therefore, multi-layer coatings provide opportunities for extending the life of die components.

The multi-layer coatings for die components are developments of the Colorado School of Mines and consist of die surface modification by nitriding or carburizing, followed by and adhesion layer, then an intermediate layer, and finally, an outer working layer. Since this is a very new technology, in-plant experience is limited but favorable and the multi-layer coatings, one of which is Ti-TiN-TiAlN-Al_2O_3, are being commercially produced.

On the horizon is a multi-layer smart coating with an embedded piezoelectric film that will allow the condition of a die component to be monitored remotely so that remedial action can be taken prior to the initiation of cracking so that die life can be further extended.

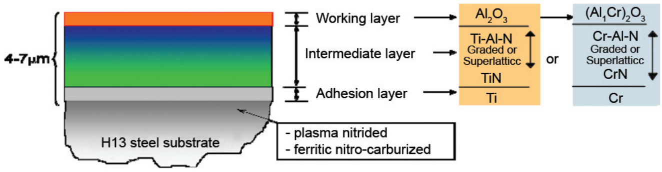

Figure 6 – *A schematic of example multi-layer coating architectures.*

Conclusion

Recent technologies exist that can assist in extending the life of die casting die components. Die casters have utilized these technologies and have achieved varying degrees of success, depending on the specific technology and cast part configuration. In limited cases, improvements in excess of four-fold have been achieved. Hence, there are opportunities for substantial improvement.

The technologies to consider are:

1. New die steel compositions
2. High thermal conductivity materials and bi-metallic die components
3. Improved cooling line placement
4. Cooling line control
5. Advanced coatings and surface treatments

Die casters who take advantage of these technologies not only extend die life, but can increase productivity and enhance product quality and consistency. These advantages work together to provide a higher degree of competitiveness in the global marketplace.

Additional Resources

- Special Quality Steel and Heat Treatment Acceptance Criteria for Die Casting Dies document
- Care and Maintenance of Die Casting Dies Manual & Checklist document
- The NADCA webinar on Bi-Metallic Tooling
- The NADCA webinar on Cooling Line Placement
- The NADCA webinar on Multi-Layer and Smart Coating Systems

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