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A NEW APPROACH TO AN OLD PROBLEM - DIE EROSION

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The technical advancements achieved throughout the die casting industry in recent years have brought about better understanding and control of many problems in the casting process. Some problems, however, which have plagued die-casters since the process was developed are still with us today. Die erosion is one such problem. The Die repair costs, and added finishing costs on castings produced in eroded dies are persistent and expensive casting problems.

The purpose of this report is to present the results of an investigation into the factors causing die erosion. The procedure for this investigation was first to analyze numerous erosion conditions and point out the ineffectiveness of the currently accepted theory on die erosion to explain their existence. Evidence is then presented to substantiate a new theory that *does* explain the existence of the erosion conditions.

The material presented will begin with a brief description of the theory that has received general acceptance throughout the industry as being the causing factor for die erosion. This is followed by evidence demonstrating the incompatibility of this theory with the existence of actual erosion conditions. The locations of the erosion conditions are then analyzed, with consideration given to certain fluid flow properties and a new theory to explain how erosion occurs. A summary of several high points of the investigation is then presented.

EROSION THEORY

Die erosion first appears as minute pits in the die steel. These pits become deeper and more numerous, until eventually, the castings produced have rough projections as shown in Figure 1. Undoubtedly, many theories have been considered over the years to explain this pitting action. Such variables as flow velocity, pressure, die steel hardness and composition, and flow direction have long been considered contributing factors. Only one theory, however, has received general acceptance industry-wide as being the causing factor for die erosion. Basically, this theory asks us to believe that the die steel is literally "washed away" by the blasting, turbulent action of the casting alloy as it enters the die cavity. Thus, the die is eroded just as a sand pile would be washed away by the action of a stream of water from a garden hose.

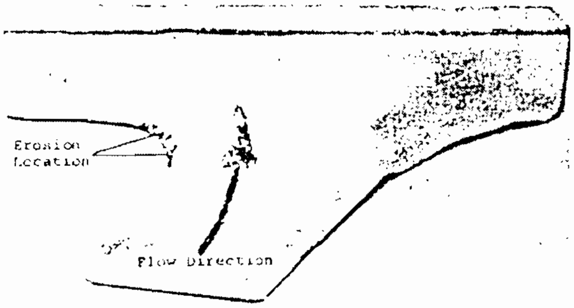

Figure 1. Erosion At Bend In Runner

ANALYSIS OF EROSION CONDITIONS

It is apparent why the above theory has gained such wide acceptance as being the cause of die erosion. The extremely high flow velocities experienced during injection would provide the necessary forces to break down the steel and thus make the washing action theory a logical one to accept.

Studies of numerous erosion conditions in zinc die casting dies, however, have provided evidence challenging the correctness of this theory. The following illustrations show erosion conditions in the runner systems of four different dies.

As can be seen in Figure 1, erosion is occurring at a bend where the runner turns to follow the contour of the part. The arrow indicates the flow direction through the runner. Obviously, the location of the erosion is such that there is no direct flow against the steel. The inertia of the high velocity flow would carry the molten casting alloy away from the die steel in this area. Thus, the area that is eroding is not positioned to receive any direct flow or washing

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action, so the accepted theory described earlier does not provide an explanation for the erosion condition.

Figure 2 shows a similar erosion condition occurring at a bend in another runner. Again, the area eroding would be an area bypassed by the flow and would not receive any direct flowing action to substantiate the washing action theory. The erosion in both Figures 1 and 2 occurs where the flow direction would indicate the least amount of direct flow impingement. These should be the least likely areas to erode.

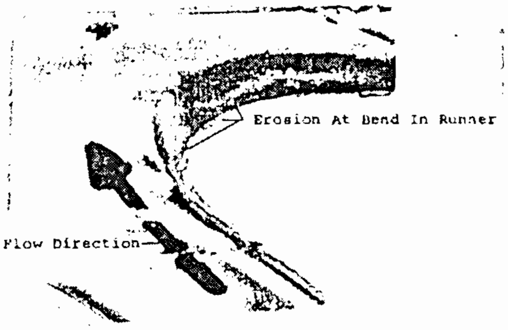

Figure 2. Erosion At Bend In Runner

Figure 3 shows erosion occurring beyond a restriction in the flow area where the sprue feeds the runner system. The logical place for erosion would be at the restricting point shown in the illustration. This area receives a direct blast from the alloy as it leaves the sprue, yet there is no evidence of erosion at this point. The area which *is* eroding, however, is beyond the rounded restriction. Again, the washing action theory does not appear to apply.

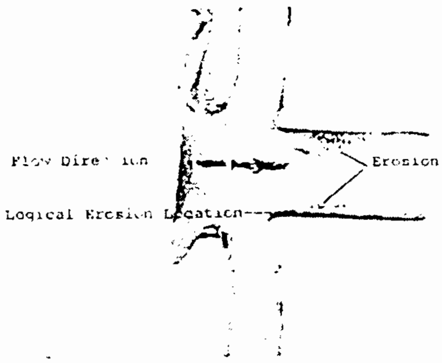

Figure 3. Erosion Beyond Rounded Runner Restriction

The erosion on the runner shown in Figure 4 can be seen just beyond the bullet-nosed dividers between runners. The logical place for erosion would be directly at the tips of the dividers as shown on the illustration. Again, however, the erosion is "downstream" from these points, in places where no evidence of any direct impingement against the steel is apparent.

The foregoing illustrations were all taken from runner systems, since erosion in these areas can be allowed to progress without harming the castings produced. Numerous similar conditions where erosion could not be explained by the washing action theory were found in the die cavities. Figure 5 shows the location of erosion and the flow direction from the feed-gate on the cross section of a zinc die casting. The erosion was occurring at an area adjacent to the gate entrance and was positioned such that there was no direct flow against the steel. Figure 6 shows another part cross-section, with erosion occurring at a point where the inertia of the high velocity molten alloy would cause the metal to flow away from the die steel rather than against it.

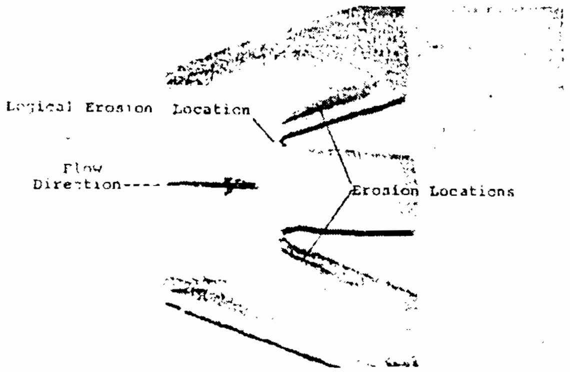

Figure 4. Erosion Beyond Rounded Runner Dividers

The need for a better explanation of the cause for these erosion conditions is obvious. Erosion, in every instance examined, was occurring at areas where the die steel would obtain the least amount of direct flow from the high velocity molten alloy, areas which should be the least likely to erode according to the washing action theory. The application to this problem of a fluid flow phenomenon known to cause pitting and erosion in hydraulic equipment provided a theory that explains why erosion existed in these areas. This theory is developed below.

FLOW SEPARATION AND CAVITATION THEORY

One characteristic common to all of the erosion locations reviewed in the above case studies was that erosion was occurring where there would be a flow separation from the die steel. The inertia of the alloy at the bends in runners, area increases, and obstructions would all result in voids in the flow pattern. Such a condition forms flow fields characterized by eddies and wakes downstream from the point of flow separation. During some conditions of separation, the local pressure may fall to the vapor pressure of the flowing fluid. When this happens, the phenomenon called cavitation occurs.

Cavitation has been associated with pitting and erosion on components of hydraulic systems for many years. Pump vanes, for example, are subjected to the eroding effects of cavitation resulting from insufficient fluid supply, causing voids to form and localized vaporization to take place.

The mechanism of cavitation-caused erosion is explained clearly in Appendix VII of the text *Elementary Fluid Mechanics* by John K. Vennard. Here Vennard uses an illustration similar to Figure 7 to show how cavitation occurs and explains how it can cause erosion at the boundary surfaces.

Figure 7A shows where the cavitation would occur. The void formed has a reduced pressure and, if reduced to the vapor pressure of the fluid, contains a swirling mass of droplets and vapor. This cavity is swept downstream into a region of higher pressure where it collapses suddenly and the surrounding liquid comes together to fill the area. When the liquid comes together as the void is collapsed, the local pressure within the liquid is momentarily raised to a very high value. It is this collapse and local high pressure that causes extreme stresses on the boundary wall. The resulting high stresses lead to fatigue, and finally, to pitting of the boundary wall.

The final steps in the cavitation process are shown in Figures 7B and 7C. This illustrates how cavitation affects the walls of a mold in a single occurrence. It should be noted that such cavities actually form, collapse, and reform many times a second.

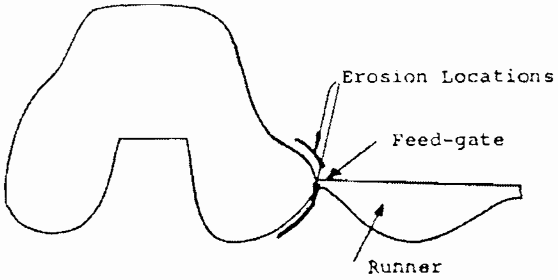

Figure 5. Erosion Locations On Casting Cross-Section

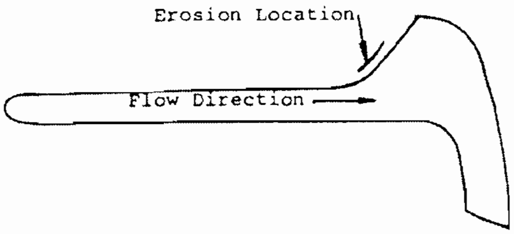

Figure 6. Erosion Location On Casting Cross-Section

Another example given by Vennard to show where cavitation and erosion would occur is shown in Figure 8. Here, the void is formed beyond the blunt end of a rounded obstruction, with erosion occurring downstream where the pressure increases to collapse the low pressure vapor pocket.

Obviously, the only remaining step in developing the theory of cavitation as a cause for die erosion is to correlate the conditions surrounding the erosion cases discussed earlier, with the flow conditions existing at the points where the fluid flow principles just presented predict that cavitation erosion will occur. The flow conditions at the rounded runner dividers in Figure 4 are nearly identical to the conditions presented in Figure 8. It can be seen that erosion is occurring at exactly the points where cavitation, according to the fluid flow principles discussed should be experienced. The rounded restriction in Figure 3 would resemble half of the rounded obstruction in Figure 8. Again the flow is deflected to form a void in the flow pattern, with erosion occurring in precisely the areas predicted to experience cavitation.

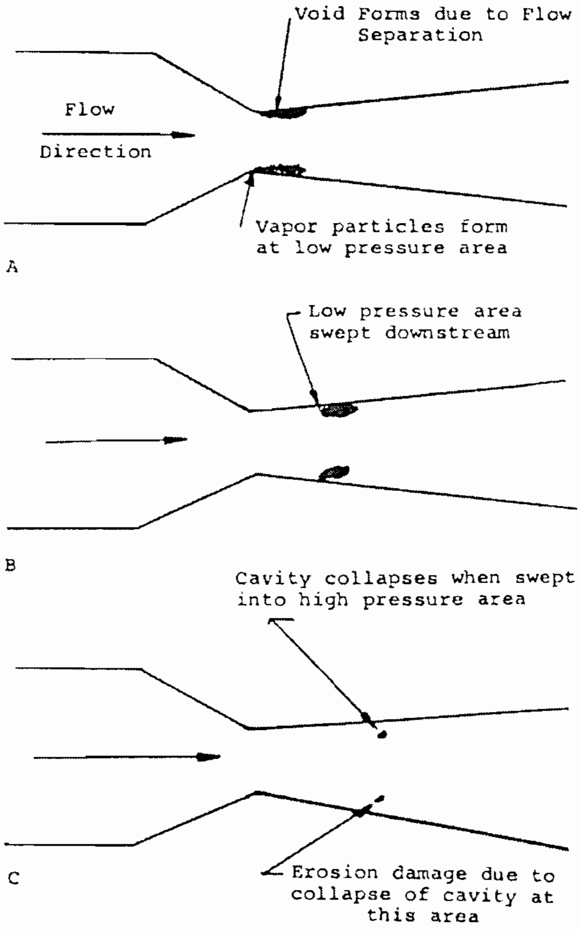

Figure 7. Cavitation Occurrence At Restriction

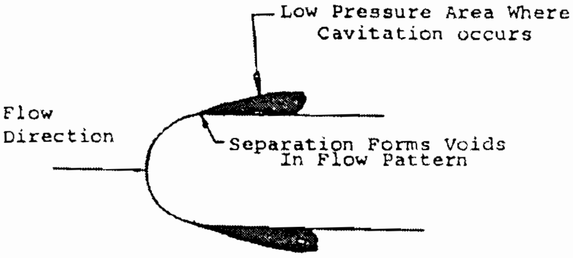

Figure 8. Cavitation At Rounded Obstruction

The flow conditions in Figures 1 and 2 are similar to those of Figure 7. The flow area is increased and the inertia of the moving fluid causes a flow separation point to form. As can be seen in both illustrations, die erosion is concentrated beyond the separation point, in areas where the low pressure cavity would be swept downstream. Again, the erosion conditions are in places where fluid flow principles predict that cavitation will occur. The erosion situations in Figures 5 and 6 are similar, since erosion takes place downstream from flow area enlargements where cavitation would occur.

The evidence presented here indicates that the cause for die erosion is the occurrence of the phenomenon known as cavitation at certain places within the die cavity during high velocity injection of molten metal.

SUMMARY

The popular theory that the die steel is washed away by the turbulent action of the flowing molten alloy to form erosion is not substantiated when applied to the actual locations of erosion conditions. The erosion cases studied indicate that the eroding areas were at places where flow separation from the die steel (rather than direct flow against the steel) was happening. Such flow separation can result in the inception of the cavitation phenomenon that has been known for many years to cause erosion in hydraulic systems.

From the evidence compiled during this investigation, it must be concluded that die erosion is caused by the damaging effects of cavitation on the die steel adjacent to the point where cavitation occurs.