Die steels and the heat-treatment of dies for use in die casting aluminum base alloys

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DIE STEELS AND THE HEAT-TREATMENT OF DIES FOR USE IN DIE CASTING ALUMINUM BASE ALLOYS

-by-

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## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Consideration of the Die</td>
<td>1</td>
</tr>
<tr>
<td>Die Casting Process</td>
<td>5</td>
</tr>
<tr>
<td>Die Casting Machines</td>
<td></td>
</tr>
<tr>
<td>Aluminum Base Die Casting Alloys</td>
<td>11</td>
</tr>
<tr>
<td>Difficulties Encountered in Aluminum Base Casting</td>
<td>13</td>
</tr>
<tr>
<td>History of Die Steel Development</td>
<td>18</td>
</tr>
<tr>
<td>Practical Requirements of Die Casting Die Steels</td>
<td>22</td>
</tr>
<tr>
<td>Methods of Evaluating Die Steels</td>
<td>28</td>
</tr>
<tr>
<td>Heat-treatment of Die Steels</td>
<td>35</td>
</tr>
<tr>
<td>Method of Heat-treating Dies of .35% Carbon, 4.50% Tungsten, 5.0% Chromium, 0.50% Cobalt Hot Work Steels</td>
<td>39</td>
</tr>
<tr>
<td>Precautions in Finishing and Using Dies</td>
<td>45</td>
</tr>
<tr>
<td>Summary</td>
<td>46</td>
</tr>
<tr>
<td>Bibliography</td>
<td>47</td>
</tr>
</tbody>
</table>
**ILLUSTRATIONS**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sketch Showing Plunger and Pneumatic Types of Die Casting Machines</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Sketch Showing Lester Type Die Casting Machine.</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>Sketch Showing Cooling Water Manifold with Test Blocks Attached</td>
<td>32</td>
</tr>
<tr>
<td>4</td>
<td>Apparatus for Intermittent-Immersion Testing of Steels for Die Casting Dies</td>
<td>33</td>
</tr>
<tr>
<td>5</td>
<td>Sketch Showing Method of Packing Die Casting Dies and Method of Sealing Boxes</td>
<td>41</td>
</tr>
<tr>
<td>6</td>
<td>Tempering Curve</td>
<td>43</td>
</tr>
</tbody>
</table>
GENERAL CONSIDERATION OF THE DIE CASTING PROCESS

Although the casting of metals is an ancient art, it was not until recent years that metals were cast in large quantities in metallic molds. The increasing demands on the industry for greater production brought about this change which essentially involves the introduction of molds capable of producing numerous castings in preference to the use of non-metallic molds which were destroyed in making the casting.

Non-metallic molds other than regular sand foundry molds are still used in various specialized fields today. However, metal molds are used very extensively for production runs where sufficient quantity of parts will permit absorption of the mold cost. The types of casting using metal molds may be outlined as follows:

1. Slush casting.
2. Pressed casting.
3. Centrifugal casting.
4. Permanent-mold casting.
5. Die casting.

Slush casting is used to produce thin walled castings of low melting base alloys. The chilled mold is filled with molten metal and immediately upon filling, the metal is poured out, leaving the thin section cooled.
at the mold wall. Various ornamental objects are produced by this method and the operation involves considerable skill in order to produce the desired wall thickness.

Pressed casting consists of pouring a definite amount of metal into a mold, the metal flowing by gravity pressure only. The inner shape of the casting is represented in the core, which is then brought down with pressure before the metal has solidified. The principles of the process permit only simple castings of open design to be made by this method.

Centrifugal casting involves the high speed rotation of a die or mold containing a definite amount of metal. A much tougher and generally superior cast iron pipe is successfully cast by this method. Many variations of the process include successful casting of steel, bronze, brass, copper and aluminum base alloys. The latter metal has been used for objects which do not have the usual cylindrical shape. In this method the metal is fed into a gate at the center of a revolving table with radial runners leading to the dies which are placed around the periphery of the table.

Permanent-mold casting includes the process of filling a metallic mold with metal which is introduced under gravity pressure only. In this process the metal solidifies in successive layers by constant fluid metal
feed from a head maintained in the gate. The process produces a sound casting but is limited to less intricate castings and for successful application the thickness of wall sections must be closely considered. This field is being extensively developed today for the casting of iron and steel.

Die casting is largely an outgrowth of the permanent mold casting discussed above. The limitations of the latter method regarding intricate castings and thin walls were the important factors in the development. Die casting is essentially the forcing of molten metals under pressure into metal molds. The cooling is usually accelerated by water cooling the dies. The dies are then opened and the castings removed.

Some of the economic benefits of die casting may be outlined as follows:

1. Die casting offers rapid production of large quantities of parts with uniformity of dimension. Commercial aluminum base castings are generally produced within dimensions accurate to within 0.0015 inches per linear inch.

2. Machining operations are reduced and often completely eliminated.

3. Die casting may often be made to produce thin wall parts which ordinarily would otherwise
involve complex punching, forming and drawing operations.

4. Solid parts of various metals may be cast into the casting, such as bushings, inserts, etc.

5. Die castings have smooth surfaces requiring little or no finishing.

6. Ornamental designs are reproduced in quantity at low costs.

7. Castings may have thin and light sections.

In all cases it must be borne in mind that die casting must be applied to large quantity production in order to absorb die cost.
DIE CASTING MACHINES

Although there are a very large number of different types of die casting machines from simple, completely hand operated types to very complicated automatic types, they have three elements in common which may be listed as follows:

1. The pressure chamber or pump wherein the metal is subjected to the periodic force required for delivery of the metal to the die.
2. The frame for opening and closing the die.
3. Relative position of the pressure chamber to the frame with respect to the metal flow.

The first of the above classification limits the machine to the type of pressure used, which may be by either plunger or pneumatic methods. In the former the metal is forced into the die by means of a piston action. Additional metal is then allowed to flow into the cylinder on the return stroke. Although this method has not been used with any appreciable success in this country for aluminum base casting or other higher melting alloys, it has been used somewhat extensively in Europe. A modification is used wherein the metal is heated in a separate furnace and dipped
into the cylinder before pressure is applied. By this method successful brass castings have been made in Europe and extensive developments are introducing this method into this country.

In the pneumatic type the metal is forced by air pressure applied to the surface of the molten metal. The pressure chamber is usually refilled by dipping down in the molten metal. The action and design of this type has led to the classification of this part as the "gooseneck". Since the pneumatic type is almost used exclusively for aluminum base alloys, it will be discussed in detail later. The sketches of Figure 1 illustrate the two principles of the pressure and pneumatic types.

The frame for opening and closing the die depends largely upon the method of gating used in the die. The die may be (1) solid sprue type (center-gated), in which the metal enters the die through the center of the one die half and then by gating is forced to flow along gates to the cavity impressions; or (2) split sprue type (end-gated), in which the metal flows through a split gate at the end of the die, half of the sprue being cut into each die half, and the metal then flowing directly into the cavity. The former method is the more extensively used and largely for multiple cavity dies of small parts. The latter method is largely applied to
Sketch Showing Representative Types of Plunger and Pneumatic Die Casting Machines.

Fig. 1.
thin flat castings where direct flow is more desirable.

The types may be classified in regard to the relative position of the pressure chamber to the frame with respect to the metal flow as (1) down-flow, (2) up-flow, and (3) level-flow. In the first type, considerable difficulty was encountered in keeping the valve operating satisfactorily with particular reference to the higher melting aluminum and zinc base alloys, since the valve is always in direct contact with the molten metal. This method has been largely discarded in favor of up-flow and level-flow types. The latter is used largely in the "gooseneck" type machines used extensively for aluminum base casting.

The writer's experience was largely obtained during his connection with the Metallurgical Development and Physical Studies Division, headed by H. A. Anderson, of the Western Electric Company, Incorporated. This experience has been confined to the pneumatic type, solid sprue gated, level-flow type of die casting machine used for aluminum base alloys. The studies concerning die steels and the heat-treatment of dies has been centered around this type of machine. Some of the more important details concerning such equipment will be briefly discussed.

The sketch, Figure 2, shows the gooseneck type
Sketch showing Gooseneck-Type of Die Casting Machine.

Fig. 2.
of machine which is similar to the machines used at the Western Electric Company. The ingot metal is introduced in the melting pot by hand, and the goose-neck lowered into the pot by hydraulic power. The metal flows into the gooseneck through the nozzle. The gooseneck is then again raised to the illustrated position with the nozzle against the gate bushing. The metal is then "shot" by applying air pressure controlled by a hand lever. After several seconds, the cores are pulled, the die halves opened, and the castings removed. The gooseneck is then again lowered, the die closed, and the cycle repeated. From sixty to ninety castings are produced per hour, depending on casting conditions and the metal used. A pressure of about 500 pounds per square inch is used in forcing the metal into the die. The die is opened and closed by hydraulic pressure operating from a motor driven oil pump. The temperature of the metal is controlled by automatic gas-fired burners operating from a thermocouple inserted in the rear wall of the casting pot.
ALUMINUM BASE DIE CASTING ALLOYS

With the advent of aluminum base die casting, a large number of alloys were used in attempts to overcome difficulties and produce superior castings. The alloys used may be roughly classified as follows:

1. The preliminary alloys which contain 3% to 16% copper and which are largely being discarded in favor of the other two classes, and copper alloys containing about 2% silicon, and also iron and zinc, the latter usually as impurities.

2. Alloys containing nickel, copper and silicon in variable amounts. The nickel is used largely for improved appearance. Its addition, however, increases the cost.

3. Silicon alloys which may or may not contain copper. These alloys have good casting properties but they do not machine as well or have the high luster appearance found in some of the other alloys, chiefly those containing nickel.

The Committee B-6 of the American Society for Testing Materials has made some very complete tests of the properties of aluminum base alloys which they have enumerated according to the following table:
<table>
<thead>
<tr>
<th>A.S.T.M.</th>
<th>Chemical Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nos.</td>
<td>Copper</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
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<td>3</td>
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<tr>
<td>4</td>
<td>5</td>
</tr>
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<tr>
<td>11</td>
<td>8</td>
</tr>
</tbody>
</table>

The above table may be limited to Nos. 4 to 11, inclusive, as the others have been judged obsolete.
DIFFICULTIES ENCOUNTERED IN ALUMINUM BASE DIE CASTING

The difficulties of die casting aluminum base alloys, as carried out on the above equipment, are rather numerous. Developments are being made rapidly due to the increasing demands of the industry. The above type of equipment, however, is representative of good equipment, and, although rapid developments will probably make important contributions in the near future, the limitation of the machine described above will serve to illustrate some of the present difficulties encountered.

Many of the difficulties which are large problems for the die casting of aluminum base alloys are still greater when higher melting alloys are considered. However, this paper will not consider the casting of other metals. The difficulties encountered in aluminum base casting may best be outlined as follows:

1. Solubility of iron in aluminum from contact of the molten casting alloy with the iron parts and the resulting contamination of the castings.
2. Contamination of the molten alloy with oxides of aluminum, which are readily formed and are soluble in the molten alloy.

-15-
3. Formation of porous castings due to the direct application of air pressure on the metal and the consequent entrapping of air in the casting.

4. Concentration of strains due to the cooling of the casting during solidification.

5. Difficulty in obtaining optimum casting temperatures for various alloys, which will correspondingly cause difficulty in casting, in addition to the segregation of constituents.

6. The general failing of the dies due to severe service to which they are subjected.

The solubility of iron in aluminum is an important factor. This must be guarded against in both casting as well as remelting. Since many castings have as much as 50% waste metal in the gates and trimmings, remelting is often an important part of the practice. The solubility of iron in aluminum is greatly accelerated by temperatures any appreciable amount in excess of the melting point of the alloy. This makes it necessary to closely guard against overheating in remelting, as well as heating in the casting pot. Cast iron has been found to be the best material for melting pots, nozzles, and goosenecks. Various non-metallic coatings have been
used with questionable benefits in regard to reducing the rate of iron solution. The working parts of the die casting machine coming in contact with the molten alloy are particularly susceptible to solution. These parts, chiefly the gooseneck and nozzle, require frequent replacement which involves interruption in operation.

The contamination of the castings, however, is a far more serious aspect of the iron pickup. Where high grade castings are needed and particularly where any machining is to be done, specifications are often used to limit the iron content to 2.0% or lower. The remelted metals from the gates, etc. usually run between 1.5% to 2.0% iron and it is necessary to mix this carefully with the low-iron virgin metal in the melting pot of the machine so that prohibitive iron contents will not result. High iron contents (over 2%) make the resultant alloy viscous and brittle.

The formation of aluminum oxides is prevalent in melting aluminum alloys due to the ready oxidation of aluminum. The oxides, chiefly Al₂O₃, are entrapped in the metal and develop serious hard spots in the castings. Although the present practice of pneumatic casting favors the introduction of oxides, much of this difficulty is inherent to the melting down of the scrap, as well as melting down the metal in the casting pot. The elimin-
tion of oxides from both of the melting operations can be largely reduced by the use of suitable fluxes which violently agitate the bath and bring the oxides along with other contamination to the surface. Careful skimming will then successfully aid in cleaning the bath. Suitable fluxes are largely chloride mixtures and are usually used one pound of flux for two hundred pounds of metal in remelting. Periodic fluxes of the casting pot should also be made with the same flux ratio. Contamination of trimmings prior to remelting is to be avoided. Oil contamination which may easily occur has led to the introduction of carbon and the subsequent formation of undesirable carbides.

The formation of porous castings is partially caused by the contact of the molten metal with the high pressure air used and the resulting entrapping of included gases. Intricate castings free from porosity are very difficult to make as the pressure used must be excessive to fill the cavities.

Internal shrinkage is also a cause of porous castings. This must be carefully considered where intricate castings are made. Internal strains and the resultant non-uniform structure are serious difficulties encountered in intricate castings.
The melting temperatures to be used vary, of course, with the alloys. It is always desirable to cast as close to the melting point as possible and yet secure enough fluidity to fill the recesses of the die. Overheating must always be guarded against due to the iron pickup previously discussed. In addition some alloys precipitate compounds when overheated and, of course, drastically change the composition of the casting alloy.

The failure of the dies is a serious problem. The dies range in cost up to $5,000 or more and early failures of such dies are highly undesirable. In the case where the design of the casting will outlive the die, maximum production from the die is, of course, desired. This is often the case and under such conditions it is advisable to expend additional funds for quality. The details of die steels and die failures will be discussed at length in the following pages.
HISTORY OF DIE STEEL DEVELOPMENT

It appears well at this time to discuss the general developments in die steels. In the early days of die casting where the process was limited to tin and lead base alloys, plain low carbon machinery type untreated steel was used very successfully. However, with the advent of zinc base alloy casting and higher production runs, the plain carbon steels were not very successful. Chrome-vanadium steels of the type .50% C, 1.25% Cr, and .25% V were introduced and satisfactorily used in the untreated condition. The introduction of the still higher melting point aluminum base alloys imposed still more severe requirements, and the chrome-vanadium steel offered poor resistance to the heat checking brought about by the excessive casting temperature used.

A chrome-vanadium steel of similar composition to the above, but with 2.25% Cr, was introduced and used with some success; but it soon became apparent that for production runs of over 20,000 castings a more superior material would be required. The 2.25% chrome-vanadium steel was then heat-treated and the inherent distortion difficulties of oil quenching this steel from 1600°F were encountered. Satisfactorily heat-treated dies gave substantial improvement but the demands of the industry
for complex castings and correspondingly intricate dies were difficult to heat-treat without warpage and frequent cracking. The best treatment, however, did not produce dies of ability to stand long production runs for precision aluminum base castings. For zinc, lead, or tin base castings, a less expensive steel (.40% C, .10% Mn, .90% Cr) suitably heat-treated was found to be satisfactory.

The aluminum base industry soon demanded dies for heavier and more intricate designs along with higher production runs and closer inspection of the finish of the cast parts. High speed steels of both 18% tungsten, 4% chromium, 1% vanadium, and 14% tungsten, 4% chromium, 2% vanadium were used with some success for small cores near the gate and other parts where the severest service was encountered. However, the severe strains set up in the actual die blocks where appreciably severe water cooling was required limited the use of such materials, inasmuch as the severe thermal alterations often caused large crack failures. In addition, dies made of such types are difficult to harden due to the high temperatures required. This difficulty in hardening is due to the possible development of brittleness from excessive
grain growth, which is promoted by subjection to the high temperatures for relatively long periods of time.

Hot work die steels of the 10% tungsten, 3.5% chromium, .30% to .50% vanadium type are being used with some success, although here again a high temperature of at least 1900°F is required for hardening and the treatment must be cautious to avoid grain growth. These steels develop heat checks, and large cracks result if used with severe water cooling. A lower tungsten type (approximately 8%) with no vanadium reduces the heat checking but not the large cracking difficulties.

Stainless steels have not been found successful, chiefly because of the necessary oil hardening and the distortion resulting from such treatment. A .60% carbon, 16.0% to 18.0% chromium stainless steel has been used somewhat successfully for some small cores and pins after having been given a short time treatment in molten cyanide at 1300°F to 1400°F.

The steel used most widely today is a type containing 4.5% tungsten, 5.0% chromium, 1.0% silicon, .35% carbon and .50% cobalt. This steel is less subject to large cracking and heat checking,
although relatively small, is still the largest detriment. The heat-treatment of this steel will be discussed later in detail as this is the steel which has been foremost in the writer's experience.

Nitriding steels for die purposes are meeting with considerable success according to various reports from the industry. Indications of the possibilities of nitriding steels were obtained from successful low temperature cyanidling (known to give a nitrogen case). Poor machining characteristics of early steels for nitriding, as well as difficulties in annealing and renitriding, have been a draw-back in their development. A development of annealing in fused chloride baths and the development of more readily machineable steels has given real impetus to this method. Some very successful results have been recently reported.

Developments along the line of substituting molybdenum for tungsten in air hardening tungsten-chromium steels and the nitriding of various steels with molybdenum, aluminum and chromium combinations are under consideration at the present time.
PRACTICAL REQUIREMENTS OF DIE CASTING DIE STEELS

The practical requirements that die casting steels should have may be outlined as follows:

1. Resistance to heat checking.
2. Resistance to severe cracking on sudden temperature change.
4. Resistance to deformation in heat-treating.
5. Resistance to general wear.
6. Resistance to the solvent action of the alloy to be used.
7. Satisfactory properties at elevated temperatures.
8. Machineability.
9. Cleanliness and uniformity.
10. Forgeability and general producibility.

The above properties may be discussed in detail.


Heat checking has always been a large factor in such industries where hot work steels are used. However, with more rigid inspection requirements and the long production runs expected in die casting, the prob-
lem of heat checking has become outstandingly important in this industry. Heat checks are due to uneven straining between the outer thin film of the die and the interior. The outer film by direct contact with the casting alloy is subjected to high temperatures which do not penetrate any appreciable amount into the water-cooled die block, and the more severe thermal alterations in the outer film causes definite rupture. These ruptures or heat checks, although slight at first, are soon increased in size by the continuation of the "thermal fatigue" and the added wedging action of the metal being introduced under severe pressure. However, heat checking troubles may be minimized considerably if dies are taken out and carefully polished after the first significant cracks are noticed. This usually occurs after about 5,000 to 10,000 castings have been made. The die is then put back in service and, when noticeable checks reappear, the die must be again removed and polished. This requires careful attention as well as production loss due to shut-downs, but if the condition of
the die is rigidly inspected and periodically reworked the ultimate life of the die will be very appreciably increased.

2. Resistance to Severe Cracking on Sudden Temperature Changes.

This condition must be especially considered where severe water-cooling methods are used. If the cooling water is carefully controlled, this is considerably lessened. However, in starting casting (either initially or after any shut-down long enough to permit the die to become cold) the cooling water is shut off to permit the die to heat up slightly. If, when the die becomes hot, the cold water is suddenly turned on, as is often the case, the sudden temperature change may actually split the die. This condition is relatively infrequent with the chrome-tungsten-silicon-cobalt steel previously discussed.


Since die castings are designed to eliminate as much machining of the casting as possible, the dies are accordingly very
intricate and the surface must be very smooth. Dies must consequently be hardened with minimum scaling to avoid expensive grinding.


The close limits imposed on the castings make it necessary to have deformation of the die at a minimum. Distortion in heat-treatment must be extremely small and consequently air-hardening steels are to be preferred over other types.

5. Resistance to General Wear.

The die is subjected to severe impact strains, as well as general abrasion. Accordingly the die must respond to a hardening that will permit a tough and hard condition to resist such stresses.

6. Resistance to the Solvent Action of the Alloy to be Used.

The die must also be resistant to the solvent action of the alloy. This is largely a matter of the condition of the die surface, although the rate of solution of various steels is different and consequently a type
of steel of low solubility in the alloy is necessary.

7. Satisfactory Properties at Elevated Temperatures.

Casting temperatures of aluminum base alloys are from 1150 °F to 1350 °F. Although small uncooled parts reach the close proximity of this temperature, the other parts of the die vary from room temperature to temperatures of 800 °F to 900 °F. Consequently, satisfactory die steels should have satisfactory properties of "red hardness" and no low areas or inverse deflections on elevated temperature tests covering a range of from room temperature to about 1000 °F.

8. Machineability.

This is an important factor when the high price of dies is considered. The chrome-vanadium steels are better in this respect than the tungsten hot-work steel. However, developments are being made in the form of additions to the latter in order to improve this condition. These added constituents are typically represented by zircon-
ium, which is being successfully used for the same purpose in other steels.


Segregations and inclusions are to be carefully avoided in die steels as they serve as sources for both "thermal fatigue" and severe cracking. In addition, segregations and associated hard spots cause difficulty in machining. Suitably large discards from tops and bottoms of ingots must be made. The melting practice should be to avoid slag inclusions, secondary piping, etc.

10. Forgeability and General Producibility.

Die steels must permit appreciable forging since dies are made from many variations in die block size. Forging practice itself must include the eliminations of seams, laps, hammer bursts, cracks, ingotism, etc.

Although the above properties are desirable in die casting dies, no one steel has been found to be foremost in all of these properties. Many investigations have been and are being made to evaluate steels; the methods are varied and in many cases extensive. These will be briefly discussed in the following pages.
METHODS OF EVALUATING DIE STEELS

Due to the expense involved in die casting dies, as well as the long length of service given by dies, it is difficult to make up dies and evaluate die steels on the basis of direct service. Accordingly, several methods of evaluating dies have been developed. In these tests it was hoped to test large numbers of promising steels and evaluate such steels. Many of the tests are still in operation and may reveal some interesting results. The author's experience is based on an immersion test with which he had hoped to evaluate steels. This test will be described in detail later. The other tests being used may be classified and described in less detail.

1. Steels Tested by Actual Service as Die Parts.

The steels to be tested are made into production gate bushings in center-gated dies. In this type of test the results are difficult to obtain since in this method of casting the nozzle is periodically contacted with the one end of the bushing and failure of the bushing usually occurs from this mechanical action before actual comparative data on heat checking can be secured. Where split gate types
(which do not use gate bushings) are used, the test is varied to use insert blocks instead. This method of testing is difficult to carry on and it requires close observation. Replacements at failure are more expensive than in using gate bushings.

Spreader pins are also used for comparative purposes in actual service. However, the purpose of this part, as the name implies, is to spread the metal out into the gate and, since it does not form a part of the casting, it is not machined to close limits. It is subjected to more severe erosion than the dies and, although it is a good criterion of resistance to solvent action, it is not subjected to conditions directly comparable to those which the die proper is subjected. The testing of steels made into small cores for a multiple-cavity die is another method used. This method carries with it close observation and where multiple cavities of appreciable numbers are used, it may cause a burden on production due to changes at failure.
2. Steels Tested by Immersion in the Casting Alloy.

In this method blocks of all steels to be tested are weighed and then immersed completely in the alloy bath. At suitable intervals they are reweighed. A variation of this test is made in rotating cylindrical specimens and thereby reducing the time of test. In either case the test is limited to the solvent action of the casting alloy.

3. Steels Tested by Alternate Immersion in the Casting Alloy.

In this method specimens of the steels to be tested are intermittently subjected to the die casting alloy. This test, which was part of an investigation on die steels carried on at the Western Electric Company by the writer, will be discussed somewhat in detail.

The test blocks made were approximately 1" x 3" x 5" and were designed to be tested four at a time connected to a central manifold. The specimens were water-cooled and the channel of the cooling water was so designed as to permit variant sections of
the specimens to be exposed to the casting alloy. A drawing showing the design of the specimen is included as Figure 3. The dipping cycle was arranged in order to conform to the approximate cycle used in the actual die casting process. A counter was used to obtain the number of immersions. The electric furnace used was controlled by a recorder which was operated from a thermocouple protected by a wrought iron tube and immersed in the molten alloy. The alloy used was the 5% silicon alloy (A.S.T.M. No. 4). Figure 4 shows a sketch of the testing apparatus.

The method is handicapped by the lack of the very important pressure factor which appears so very influential in die failure. However, the adoption of a testing method which would include this factor would involve a very complex set-up and it was believed that the test as used would offer important comparative data.

The test as run was accompanied with extreme operating difficulties. After very
Sketch showing Cooling Water Manifold with Test Blocks Attached.

Fig. 3.
Electric Furnace

Apparatus for Intermittent-Immersion Testing of Steels for Die Casting Dies.

Fig. 4.
successful operation for 15,000 immersions, sticking of the molten alloy to the test blocks became a serious factor. Methods of fluxing, variation of specimen and alloy temperatures and various mechanical strippers were all tried with discouraging results. The test, in general, required very close observation. After approximately 50,000 dips, little comparison could be affected of the four steels tested. Several pot failures occurred due to iron solution and extensive shut-downs were necessary. Due to the time required for comparison, definite results have not been made as the test has not been completed. However, the time factor and difficulties encountered in operation will undoubtedly limit this method of testing to a small number of steels.
HEAT-TREATMENT OF DIE STEELS

In an attempt to develop a satisfactory method of heat-treating die steels, several possibilities were apparent and investigated. The most encouraging was developed in detail and adopted as a production method.

The die steels under consideration all had hardening temperatures of 1800°F and higher. It was, therefore, necessary to consider the following factors:

1. scaling;
2. grain growth;
3. distortion;
4. uniformity.

With these paramount considerations, the studies were conducted along four methods of hardening as follows:

2. Heat-treating in open fire using protective coatings.

1. Heat-treating in Fused Salt Baths.

These studies were limited to the use of fused barium chloride which offers suitable properties for use at the desired temperature and is used in the industry for treating steels of similar high temperature hardening.
ranges. It was necessary in the treatment for the large die sizes that the dies be in the salt bath for appreciable periods of time in order to permit such sections to be uniformly heated. Accordingly, tests were made subjecting test blocks to molten barium chloride from periods of time from one to three hours. Surface pitting was apparent when such blocks were subjected for periods exceeding one hour. This surface condition was coupled with the difficulty associated with the practical aspects of maintaining large molten baths. Graphite crucibles are necessary for containers and the general difficulties inherent to maintaining such baths at the required temperature appeared impractical for the large dies under consideration. The other methods were then investigated.


Although this method is used for heat-treating small tools where relative length of exposure to high heats is small, it was necessary to develop a material that would adhere uniformly for long exposure and would
flake off during quenching. A very large number of materials were tried, including boracic acid, porcelain slips, glasses of various melting points, chromium plating, etc. None of the materials adhered uniformly for exposures of any appreciable time over thirty minutes. In general, the results of this method were very discouraging.


This method was tested by placing test blocks in a sealed pot. The test specimens were placed on a steel plate, resting on a shallow bed of charcoal mixed with 3% to 5% of sodium carbonate. The specimens were accordingly not in direct contact with the charcoal. Some evidence of carburization was observed, and this, along with the difficulties of the very careful handling required, led to the temporary discarding of this method.


When such type of hardening could be used, it appeared very promising. Such method of heating could not be used with the higher tungsten steels because long exposures at tempera-
tures of 1800° to 1850°F were not sufficient to effect uniform and sufficient solution of carbides. Using higher temperatures in this method involved dangers of overheating and subsequent grain growth and brittleness, as well as difficulties in obtaining suitable packing mediums for such temperatures.

The 4.5% tungsten, 5.0% chromium, 1.0% silicon, 0.50% cobalt steel, on the other hand, could be satisfactorily hardened at temperatures of about 1800°F. In addition long exposures of this type of steel to this temperature did not incur appreciable grain growth. Production dies were made of this steel and efforts were concentrated to develop the heat-treatment to a production basis. The details as developed will be discussed in detail.
METHOD OF HEAT-TREATING DIES OF 0.35% CARBON, 4.50% TUNGSTEN, 5.0% CHROMIUM, 0.50% COBALT HOT-WORK STEELS

Packing in spent charcoal and similar mediums had been used with questionable success. Carburization was possible by these methods and since carburization was possibly a promoting factor in subsequent heat checking, these methods were uncertain. In the attempt to use an inert packing medium "Aloxite" was used with splendid results. The particles of "Aloxite" stuck to the die in some places so that a wrapping of asbestos was used prior to the packing. This offered good results as the asbestos parted readily from the die and did not affect the surface.

The die to be hardened using the above packing principle is first cleaned with suitable solvent to remove oil and grease. All holes and grooves (other than water-cooling holes) are then packed with asbestos rope or shreds. The die is then carefully wrapped with asbestos sheet, which is held in place with paper sealing tape. The corners are well reinforced with asbestos sheet. The die is then placed in a heat-resisting box of such size as to permit one to three inches of packing medium surrounding all sides of the die. Thin sheet iron plates are placed against the asbestos at the sides of the dies to prevent the packing medium breaking through the asbestos.

-39-
The packing medium, "Aloxite", is the fused aluminum oxide made by the Carborundum Company and is used in 12 to 16 mesh size. One part by weight of aluminum powder is mixed with five hundred parts of "Aloxite". This packing material is then packed tightly around the dies. A ridge of about one-half inch depth is then made around the top of the box at the walls, and this groove is then filled with thin copper scrap, such as wire or tinsel. The shoe-box type cover is then placed on the box and the whole inverted. A seal of fire clay and low melting lead borate is then made. This method of packing and sealing is shown in the sketch, Figure 5.

The box is then placed (lid side down) in a muffle type cold furnace of electric, gas or oil-fired type. The furnace is heated at the rate of 100°F per hour except where difficulties of firing below 1000°F are encountered, as in oil or gas-fired furnaces. In such cases the box can be heated to 1000°F but should be held for a total time of ten hours before this temperature is exceeded. The furnace should then be fired at the rate of 100°F per hour. When the furnace reaches the hardening temperature, it should be held at that temperature two hours for each inch of die section (minimum of six hours).
Sketch Showing Method of Packing Die Casting Dies and Method of Sealing Boxes.

Fig. 5.
The box is then removed and the die carefully removed from the box. The die is then stripped of adhering asbestos and permitted to quench in still air. After the die has reached handling temperatures but has not cooled to room temperatures, a Brinell hardness reading is taken as a means of guidance in tempering. Inasmuch as dies of varied thickness cool at different rates, the hardness will vary from 430 to 512 Brinell, and, accordingly, the drawing temperature will vary in order to secure the desired 387 to 430 Brinell hardness. The graph, Figure 6, shows the proper tempering temperature for the hardness secured after hardening.

The tempering is carried on in an electric furnace of suitable size and having close temperature control and uniform distribution of heat. The dies are heated to the tempering temperature and held for two hours for each inch of thickness, or a minimum hold of five hours. If the hardness of the die is still in excess of the desired hardness, the die is cautiously retempered. If the die has dropped 40 or more points Brinell but remains too hard, it should be retempered at 10°F less than the prescribed temperature. If the die does not lose 40 or more points in the first tempering operation and is still too hard, the same tempering temperature is used for retempering. If it again
does not respond, the temperature should be raised 20°F.

If the die softens to below the required 387 Brinell, it will require rehardening. Prior to pack hardening the die is annealed by the same packing method as used for hardening, except that the die is heated to 1575°F and allowed to cool in the box. The die is not removed but then rehardened in the same manner used in the initial hardening.

Production dies heat-treated by the above method under the supervision of the writer have produced production runs as high as 250,000 castings.
One of the most important factors to be considered in securing die life is the proper care of dies. The care should not end with heat-treatment but the die should be carefully finished and cautiously used. When the die is first used, a heavy oil spray should be used frequently. As the die becomes used, this spraying may be reduced. At the first appreciable appearance of heat checks, the die should be removed and carefully polished, as previously outlined. When starting die casting the die should be permitted to be heated cautiously with little flow of cooling water. As the die reaches the desired casting temperature, the cooling water should be gradually increased. Sudden increases in cooling water should be avoided as they may cause severe cracking. In all cases the die should be considered as a very important and even delicate part of the equipment and should always be used and handled most carefully.
SUMMARY

The general considerations of aluminum base die casting with particular reference to the use of pneumatic type machines has been discussed. General qualifications for dies and a brief discussion of die steels has been submitted. The methods of testing steels were discussed, and the particular intermittent immersion testing method developed by the writer has been described and illustrated in detail. The steel found to be the most successful in the author's experience - the 4.5% tungsten, 5.0% chromium, 0.50% cobalt, 1.0% silicon hot-work steel - along with the developed method of pack hardening is presented. This steel when so heat-treated and carefully used has been giving excellent results in production.
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ORIGINAL DRAWINGS