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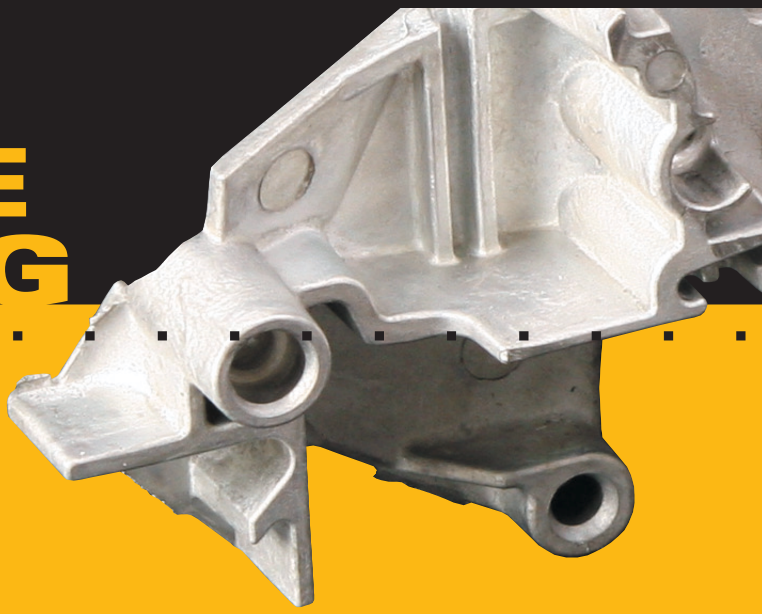
DIE SURFACE ENGINEERING



NADCA

North American Die Casting Association

EVALUATION OF COATINGS FOR DIE SURFACES

R. Shivpuri, Ohio State University

Business Benefit: This project provides the die caster with information about the benefits of various coatings – particularly on core pins – which can reduce downtime and provide cost savings ranging up to $25,000 per production run.

Project Objectives: Depending on their location, die surfaces experience die washout, soldering and heat checking during a typical die casting operation. For example, surfaces on core pins experience washout and soldering, while those on the die cavity and inserts exhibit thermal cracking. In previous NADCA projects, hard thin coatings were shown to enhance the resistance of the die surfaces to these failure phenomena. The objective of this project was to evaluate coatings and surface treatments for their performance under production conditions.

Approach: A four-step approach was used to evaluate the effect of coatings:

1. Coating Survey: Die casters and coating suppliers were surveyed for their use of die coatings on production dies.

2. Coating Identification: Based on the feedback from the die casters and the knowledgebase from literature, a large number of coatings and surface treatments were identified for their potential suitability for die casting die applications.

3. Laboratory Experiments: Laboratory experiments were set up at the Ohio State University to screen the coating and surface treatments for their resistance to washout and soldering. Coatings and surface treatments were ranked according to weight loss and soldering tendency in dip tests.

4. Production Tests: Coatings selected from laboratory tests were considered for production evaluation. Ganton Technologies, Doehler-Jarvis, General Die Casting, Premier Tool & Die Cast Corporation, and Pace Industries were evaluated for possible production evaluations. Eventually, tests were carried out at Pace Industries in Monroe, MO and Premier Tool & Die Cast Corp, Berrien Springs, MI.

Results: A two-cavity die for a body valve was chosen for evaluation at Pace Industries. The moving core pins for this die experienced soldering that required frequent cleaning, with dies being dissembled for pin replacement every 15,000 shots. These core pins were coated with four selected coatings -- CrN, CrC, TiN and VC-- applied by PVD and diffusion processes. Minor soldering was observed on some coated pins, which could be easily cleaned. However, the entire production of 180,000 parts could be completed without die downtime.

Two 16-cavity dies for making engine mounts were selected at Premier Tool & Die Cast. These dies experienced severe soldering problems on round and oval core pins very early in the die casting process causing ejection problems. Eight coatings and surface treatments were evaluated. All of them reduced the soldering tendency of the core pin, with chromium carbide and ferritic nitrocarburzing providing the best results.

Implementation Strategy: The focus of these projects was on washout and soldering experienced on core pins and inserts in high volume multiple cavity dies. There is no substitute for effective internal and external cooling of pins. However, this may not always be possible. Core pins that are long and have a small diameter are especially vulnerable to overheating and soldering. They are also the most difficult to cool internally. The second effective means of reducing soldering is effective lubrication. Well-lubricated and cooled pins seldom solder except when the pins get very hot and react with the cast metal.

Coatings and surface treatments are definite solutions to consider for washout or soldering problems. If the pins are not over heated and the cast metal surrounding the pins (modulus) is small, surface treatments such as glow nitriding, solvenizing and ferritic nitrocarburizing should be considered. For greater metal volume surrounding the pin, which is water cooled, PVD coatings (applied at temperatures below tempering) such as CrC, CrN and TiN provide excellent protection. For more severe cases, or if the pin is not internally cooled, high temperature CVD coatings such as thermo-reactively diffused vanadium carbide is the best option.

When the erosive conditions are very severe – for example near the gate in large castings – thin hard coatings are not the best solution and welding of hard facing alloys can be used locally.

Wash out and soldering are the primary reasons for large down times and the need for repair and replacement of dies, cores and inserts. Down times can be due to frequent cleaning of soldered material, the need for core pin replacement and ejection problems due to part sticking in the die.

The cost of the pins and coatings is insignificant compared to the savings realized by reduced down times. Case studies demonstrate that savings in the order of $25,000 over a production run are not uncommon. This does not take into account the gains in lead times due to the use of coatings. The issue is not "Whether to use coatings?" but "What coatings to use?"

Case Study #1

Pace Industries

Problem: A two-cavity body valve die of H-13 steel (46-47 HRC) was being used with A380 aluminum alloy at 1280°F on a 600-ton machine with a 45-second cycle time. The moving cores had to be cleaned after every 30 minutes and the die disassembled every 15,000 shots for pin replacement. Die down times were very high and frequent stoppage contributed to longer lead times.

Implementation/Action: The procedure required to first evaluate the thermomechanical conditions that the surface sees during production. Next, selected coatings and surface treatments were evaluated in the laboratory set up at Ohio State. The best coating candidates were then to be applied on the pin surfaces. These pins were evaluated in the production die at production conditions. The pins were to be monitored for their resistance to soldering. The failed pins were to be analyzed for coating failure. Based on the service history of different candidates and failure analysis, recommendations were to be made for future use of these coatings and surface treatments in die casting.

The coatings CrN, CrC, TiN and VC were identified as possible candidates based on their resistance to soldering in OSU tests. These coatings were then applied on the core pins received from Pace. The pins were measured, weighed and characterized (coatings were also applied on sacrificial pins for analysis). The coated pins were assembled in the die. An uncoated pin was included as a benchmark but had to be replaced by a coated pin due to severe soldering. The four coated pins (two cavities, two pins per cavity) were then monitored for their soldering tendency.

An insitu evaluation was done at 33,895 shots.

Results: All the pins survived the entire production cycle of 127,500 except CrC, which was removed from service and replaced by another CrC as the coating was damaged during cleaning with 600 grit paper.

Production continued for the entire production cycle without a single down time. Savings of $24,642 were reported by Pace due to reduced downtime and no loss of production.

Case Study #2

Premier Tool and Die Casting Corp

Problem: Two 16-cavity dies, H-13 (HRC 46-49), are used to die cast engine mount supports at 1,300 shots per day. A380 aluminum was the alloy with a furnace temperature of 1250°F and a 45-second cycle time on a 600-ton machine.

Core pin solder, pin failure (one to four pins per production run) and ejection problems (parts sticking in the ejector half) were the primary reason for extensive down time. Dies had to be disassembled once every 5,000 cycles for maintenance and pin replacement. Down times and pin costs were high.

Action/Implementation: The procedure required to first evaluate the thermomechanical conditions that the surface sees during production. Next, selected coatings and surface treatments were evaluated in the laboratory set up at Ohio State. The best coating candidates were then to be applied on the pin surfaces. These pins were evaluated in the production die at production conditions. The pins were to be monitored for their resistance to soldering. The failed pins were to be analyzed for coating failure. Based on the service history of different candidates and failure analysis, recommendations were to be made for future use of these coatings and surface treatments in die casting.

Thermo mechanical conditions were first established by analyzing the gate designs, the temperature of the metal, the contact times and the modulus of the casting (casting volume to pin volume). Based on these conditions coatings and surface treatments were selected for laboratory evaluation: Three surface treatments (ultraglow nitriding, ionwear and ferro-nitro-carburizing), three PVD coatings (CrC, CrN and BC), one high temperature diffusion coating (vanadium carbide) and one duplex coating (CrN on a shot peened surface) were chosen for evaluation.

Coated pins were run in production and monitored for soldering and coating degradation during the entire production cycle of 32,269 shots.

Results: Chromium carbide and vanadium carbide coatings performed the best, followed by ferro-nitro-carburizing surface treatment. They had only slight soldering that was easy to clean. Glow nitriding also showed considerable progress.

Premier is currently using ferro-nitro-carburizing on all dies with significant savings in down times. VC is not being used because of its higher cost. ■

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COATINGS FOR DIE CASTING DIES

R. Shivpuri, Ohio State University and
P. Ried, NADCA Die Surface Engineering Task Force

Business Benefit: This project provides die casters with information die coating technologies to improve die life by reducing soldering and washout problems.

Project Objectives: Die casting dies used for aluminum die casting undergo wear failures due to repeated exposure to molten aluminum. Two principal wear failures are:

- **Soldering –** the welding of the aluminum to the H-13 die steel
- **Washout –** cavitation pits caused by the impinging melt particles

To study the mechanisms of soldering and washout, a multitude of experiments have been carried out around the world. The study of the above mechanisms enables the development of protective barriers to resist them. Experiments have been conducted at the Ohio State University and elsewhere to evaluate the efficacy of coatings and surface treatments in combating soldering and washout.

The objective of this project was to prepare a document that provides information on common coating technologies; provides laboratory test results on coating behaviors; and reports on the production evaluations that have been carried out at various die casting plants around the world.

Approach: The approach taken was to prepare information that could be summarized in a written report in three areas. These were:

1. A review of the various surface treatments and coatings used in the die casting industry.

2. A compilation of the laboratory tests that have been conducted to study soldering and washout.

3. Detail the in-plant evaluations conducted throughout the world pertaining to improving the resistance of die casting dies to soldering and washout.

The general topics included in these three areas are summarized below.

Section 1

The first topic was a review of the various surface treatments and coatings used in the die-casting industry for improved die life. The main surface treatments and coatings evaluated were:

- Nitrocarburizing
- Liquid Nitriding
- Ion Nitriding
- Physical Vapor Deposition
- Chemical Vapor Deposition
- Thermoreactive Deposition/Diffusion
- Pack Cementation

Section 2

This topic included a compilation of the laboratory tests conducted at OSU and elsewhere to study the phenomenon of soldering and washout. These tests were conducted on both untreated H13 pins, and coated and surface treated H13 pins. The laboratory tests comprised of three different types: dip tests, rotation dip tests, and tests carried out in die casting machines. These tests compare different coatings in laboratory conditions and are of limited use in predicting die life under actual operating conditions. This section contains the following topics:

- Effect of heat treatment, melt composition, melt temperature and specimen rotation rate on soldering tendency
- Effect of die steel composition and effect of oxidized layers
- Effect of metallurgically and mechanically bonded coatings
- Effect of duplex treatments
- Effect of melt temperature, gate velocity and substrate hardness on the washout characteristics

Section 3

This section provided details of the in-plant production evaluations, which include the test conditions, the nature of the coatings and some of the results and observations pertaining to the relative performance of the given coating. The production evaluations were taken from peer reviewed published literature.

Following is the summary of the production evaluations discussed in this section:

- A field trial evaluation which discusses the work done at Centre Technique des Industries de la Fonderie, France in Lachenal Foundry (France)
- The work done at Bernacci Carlo, s.a.s, Alutek, Carmagnola and Politecnico di Milano, Italy, is reviewed in this report
- This evaluation is from work done at Roders DruckguB GmbH, Soltau Germany
- This evaluation talks about work done at the Toyota Central Research and Development Labs, Inc. Aichi, Japan, Aichin Keikinzoku Co., Ltd., Toyama, Japan, and Arvin TD Center, Columbus, IN
- This evaluation also discusses the work done at Toyota Central Research and Development Lab, Japan in 1972; the

efficacy of carbide coated core pins in reducing soldering was tested in a field test

• This trial is the first Beta test site for a NADCA/CMC sponsored project at OSU at Pace Industries in Missouri

• This trial is work done by OSU in 1997 at Premier tool & Die Cast at Berrien Springs, MI

• The last production evaluation discusses the work done by Centres Technique des Industries de la Fonderie, on a die that produced domestic flatiron bases in France

Results: The goal of this project was to provide a summary report for use by the die casting industry on die coating technologies and the research that has been conducted worldwide on improving die life through the use of coatings and surface treatments. The report has been captured electronically in the form of a CD that is available from NADCA. The CD is titled, *"Soldering Behavior of Surface Engineered Die Casting Dies"* and can be requested as 510-CD from NADCA.

Implementation Strategy: Die casters now have a baseline tool to use when trying to solve soldering and washout problems in die casting dies. This report can be used to guide those responsible for improving the performance of die casting dies in their efforts to improve the life of die casting dies. ■

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DEVELOPMENT OF SURFACE ENGINEERED COATINGS FOR DIE CASTING DIES

J. Moore, Colorado School of Mines

Business Benefit: This project provides the die caster with a better understanding of die failure mechanisms and identifies several possible die coatings that could be used to improve die life.

Project Objectives: The objective of this research was to develop an "optimized coating system" for die casting dies using fundamental scientific principles to minimize the effects of soldering (wetting), erosive wear, thermal fatigue and corrosion and oxidation. A wide range of coatings were examined, with the best of these being identified from both experimental data and from in-plant performance measurements.

Approach: Die failure is a constant problem that faces all die casters and results in substantial losses of time and money. The major mechanisms leading to premature die failure are:

- Soldering (wetting)
- Erosive wear
- Thermal cracking (heat checking)
- Corrosion/oxidation

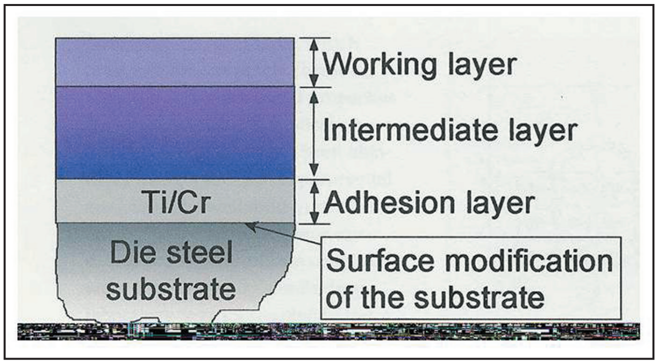
The interaction of the die and the surrounding environment plays an important role in initiating soldering, micro-cracking, crack propagation, and finally, catastrophic failure of the die. During the die casting process, the die and die components are subjected to various thermal influences. Metal injection, cooling lines, dwell time, spraying with lubricants and the extent of the cycle time are some of the factors that influence the heating and cooling of die components. These factors combine to produce chemical wetting and interaction between the liquid metal and die surface, high residual stresses and progressive softening of the die material that in turn promotes heat checking and thermal fatigue.

Previous research and evaluation of die casting tooling failures has shown that due to the complexity of die casting die failures, it is unlikely that a monolithic coating will provide the optimum system for any specific die casting application. Accordingly, this project seeks to develop coating systems that incorporate specifically engineered, multi-layered or graded architectures. A schematic diagram of such architectures is shown in Figure 1 (above right).

The conceptual design of such an optimized coating system incorporates four sections of the total coating architecture as outlined below:

- Surface modification of the substrate, such as plasma nitriding or ferritic nitro-carburizing
- A thin (50-100 nm) adhesion interlayer, such as Ti or Cr, between the substrate (H-13) and the coating system
- An intermediate layer that facilitates "accommodation" of thermal residual stresses, as predicted using FEM
- An outer, "working" layer, that exhibits acceptable properties to meet the application requirements, such as low wettability with liquid aluminum, coupled to high wear and corrosion/oxidation resistance

Figure 1. Optimized multi-layered coating system for die casting



Thus, each layer of the coating's architecture provides a specific function, and the success of the multi-layered coating system lies in the synergy of the properties and functions of each layer.

Results: During this project, 14 working layer films, including six commercial coatings, were analyzed for wettability, as well as tribological, adhesion and wear testing. A "wettability index" and a "wear index" were determined for each of these films.

The six commercial coatings were:

1. A graded Cr-N film with a thin (≈100 nm) Cr adhesion layer deposited by cathodic arc evaporation.
2. A Cr-C/Ti-Al-N bi-layer film with a thin (≈100 nm) Cr adhesion layer deposited by magnetron sputtering.
3. A graded Mo-Zr-N coating with a thin (≈100 nm) Ti adhesion layer deposited using closed field unbalanced magnetron sputtering.
4. A tiN/TiAlN multi-layer coating deposited using unbalanced magnetron sputtering with a thick (≈3.5 μm) Cr adhesion layer deposited using electrochemical deposition.
5. A graded Cr-N film with a thin (≈100 nm) Cr adhesion layer deposited by magnetron sputtering.
6. A control sample of a ferritic nitro-carburized H13 pin.

In addition, a robust finite element model (FEM) was developed that is capable of predicting suitable intermediate layers that are efficient in accommodating the thermal and mechanical stresses that arise from the shot cycling process. An important role played by FEM is to minimize the trial-and-error experiments in the identification of suitable intermediate layers and coating architectures. Once an optimum group of candidates for the working layer or film has been identified, FEM can be used to design the overall optimized coating architecture in line with the principles presented in Figure 1.

The results of the findings in this project can be summarized as follows:

- All five of the optimized commercial coating systems were superior to ferritic nitrocarburized core pins examined in an in-plant trial for aluminum die casting.
- A reaction sequence has been postulated that results in soldering and chemical attack between the H-13 die steel and liquid aluminum for both uncoated and coated H-13 dies.
- Evidence has been found for the joint action of chemical attack and thermal fatigue cracking.
- Maintaining the integrity of the coating is vital in offsetting degradation of H-13 tools steel and prolonging the life of H-13 dies.

Implementation Strategy: The results of this project provide better understanding of die failure mechanisms. The project has also identified several possible die coatings that could be used as parts of a multi-layered optimized coating for die casting dies. Die casters should actively participate in casting trials utilizing these optimized coatings for specific applications. Significantly longer die life appears to be possible through the development and application of specialized coating systems. ■

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ELECTROCHEMICAL REMOVAL OF HARD WEAR-RESISTANT THIN FILM COATINGS FROM STEEL SURFACES

B. Mishra & J. Moore, Colorado School of Mines

Business Benefit: This project provides the die caster with information about cost-effective methods for the electro-mechanical removal of failed or damaged hard wear-resistant coatings.

Project Objectives: Hard coatings are often applied to dies to prolong their service life, improve tool performance and to reduce total tooling-related costs. However, these coatings may fail, due to wear or even accidental damage, without damaging the substrate material. Therefore, it is important to be able to remove the remaining non-uniform coating without damaging the surface finish and shape of the substrate so the die can be returned to service. The objective of this project was to identify or develop a cost–effective method to remove these hard wear-resistant coatings from dies.

Approach: The microelectronics industry uses DC or RF plasma etching to remove layers of ceramic coatings such as titanium nitride and silicon oxide. This technique is slow, requires specialized tooling and typically removes only a few hundred angstroms of film thickness. For planar surfaces, chemical mechanical polishing (CMP) is also employed. However, CMP has limited use for the non-planar surfaces found on die casting dies.

An aqueous electrochemical technique has been investigated in this research. PVD titanium-aluminum nitride and chromium carbide coatings have been used to represent the two prominent surface layers used commercially on tools steels. The technique has been used at near-ambient temperatures and with water-based solutions where the process has been designed to accommodate several components with identical substrate and film layers.

The technique uses mixtures of strong acids – such as sulfuric acid, hydrogen chloride and nitric acid (aqua-regia) – and the strong base, sodium hydroxide. Potential pH conditions have been researched to determine the regime where the ceramic coating will preferentially dissolve without affecting the steel substrate. Substrates were evaluated for the extent of the coating removed. Cylindrical shapes, such as core pins and drill bits, have been used to determine the initial process conditions. The process can be scaled up to be useful for all complex shapes as long as there is electrolyte access to the surface.

Results: A process has been developed to remove hard wear-resistant thin film coatings from the surfaces of steel dies. Both TiAlN and CrC coatings were completely removed with the following conditions:

- **TiAlN Coating**
  - Potential: 12-15 volts.
  - Temperature: 50ºC
  - Solution: 0.1 M NaOH
  - Anodic current density: 2.5 – 3.0 A/cm2 Stirred Solution
  - Time for removal: 10 minutes for 5 microns (3.5 micron chromium + 1.5 micron TiAlN.
- **CrC Coating**
  - Potential: 10 volts
  - Temperature: 25ºC
  - Solution: 0.1M NaOH
  - Anodic current density: 1.0 A/cm2 Stirred Solution
  - Time for removal: 90 minutes for 7.5 microns CrC coating.

The characteristics of the process are the following:

1. Restoration of the die is effective to parts damaged only in the coating by oxidation, abrasion and/or wear-erosion. The process cannot repair the parts of the die with damaged or cracked substrates, however, unless a separate electrochemical substrate polishing step is employed for superficial surface refinishing. In this case, the substrate dimensions are likely to change. With the thin film regenerated by removal and re-deposition, the life of the die can be extended to as much as the original life of the coated component provided the substrate is not damaged. Heat checking limited to the coating, however, can be repaired by removal.

2. The process will be easy to apply and economical once optimal conditions are fully developed. It will not require special tooling. Thus, the coating supplier or the tool shop can easily apply the results of the research and adopt the removal technique. The die user could strip the coating and get it recoated or the coaters could remove the residual film from the used dies.

3. Stripping is a thoroughly anodic dissolution process. Therefore, it will not cause any harmful side effect such as hydrogen embrittlement because hydrogen evolves only on the cathode.

4. Process consumables include only chemicals and a small amount of power. Equipment hardware comprises a chemically inert container, electrodes (reference and working), an electrolyte heating arrangement and a low voltage – low amperage DC power supply. A substrate washing and cleaning step follows the electrochemical removal of the damaged coating. Commercial equipment manufacturers such as Perkin-Elmer and DG&G-PARC can provide the equipment that has been used during the research program. The cell dimensions can be determined and fabricated by the process users, based upon the throughput requirements.

5. The process will allow an easy, fast, inexpensive, safe and effective operation, permitting the use of existing environmental procedures for clean-up and disposal of used acids/organics.

Implementation Strategy: Die casters now have a method to remove and repair hard wear-resistant coatings on dies. The necessary conditions have been established for both TiAlN and CrC coatings. These procedures should be used to increase the performance of dies in production and reduce the cost of repair. ■

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A LABORATORY TECHNIQUE TO INVESTIGATE SOLDERING IN ALUMINUM DIE CASTING

Dr. Augusto Kunrath, Colorado School of Mines

Business Benefit: This project provides the die caster with information for the rapid evaluation and comparison of commercial die material, surface treatment and coating systems prior to testing in actual die casting operations.

Project Objectives: One of the most significant failure modes in aluminum die casting is the adhesion/welding of molten aluminum to the die, which renders the die unsuitable for further use. This phenomenon is called soldering and is responsible for reduction of die life with consequent increases in process costs. Several publications on soldering agree that the underlying mechanism is the chemical interaction between aluminum and the die surface. Binary aluminum-metal (iron in the case of steel dies) intermetallic phases and sometimes ternary (Al-Si-Me) compounds are formed during reactions between the die material and the aluminum alloy.

Approaches used to lessen soldering effects include the use of alternative die materials and/or surface treatments as a means of hindering or stopping the chemical interaction with the aluminum alloy. A second way to reduce or eliminate soldering is to separate the tool steel from the molten aluminum by coating the die surface.

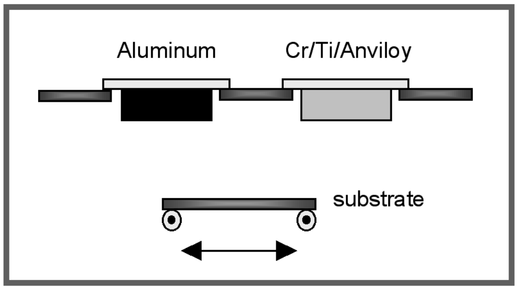
The objective of this project was not to investigate the whole soldering process, but to establish a novel technique for studying soldering reactions between die materials or coatings and aluminum. Even though the test conditions do not replicate die casting process conditions, the results are representative of the reaction behavior for each system. Because all samples are produced in the same way, the data obtained can be used to compare candidate coatings or die materials. Therefore, this technique could become an important tool in the selection of new coatings or die materials for aluminum die casting applications.

Approach: The concept of this project was to monitor these reactions as they occur, using differential thermal analysis (DTA) with further characterization of the products by x-ray diffraction (XRD). For reactions having an activation energy (Q), three or more DTA scans at different heating rates produce enough information to determine Q. In order to determine and compare the behavior of die materials and coatings reacting with aluminum, DTA samples were prepared using thin films of the candidate materials.

The materials studied in the presence of pure aluminum were: AISI H-13 tool steel, Anviloy® 1150 (including oxidized layer), crystalline alumina (Al2O3) and CrN and TiN coatings. For the thermal analysis, a differential scanning calorimeter (Netzsch DSC Model 404) was used. Experiments in the DSC were run with 5 mg samples at four different heating rates (5, 10, 15 and 20K min-1) from room temperature to 1273K (1000ºC, 1832ºF). Phillips X'Pert PRO x-ray diffraction equipment was used to characterize samples before and after thermal analysis.

In order to produce samples compatible with the DTA technique, freestanding films containing aluminum and die materials or selected coatings were prepared by physical vapor deposition (PVD), (see Figure 1). The film couples were produced in the same chamber without breaking vacuum between depositions. Films consisted of alternate layers of aluminum and the test material having a total thickness between 4 and 5 µm. Aluminum films were typically 0.9 to 1 µm thick, TiN and CrN films were 1.2 to 1.3 µm thick and Anviloy films were 0.7 to 0.9 µm thick.

Figure 1. Schematic representation of the deposition process (1a) used to produce the freestanding multilayer films used in the DSC and XRD (1b).



(1a) Deposition Chamber

(1b) Freestanding Film

Because the ferromagnetic character of the steel prevents the use of "conventional" magnetron sputtering, the "steel" films were obtained by sputtering an H-13 circular target using an anode layer type multi-cell ion source from Advanced Energy. Aluminum and Anviloy films were obtained by magnetron sputtering of the source materials in argon and TiN and CrN films were produced by the reactive magnetron sputtering in nitrogen of titanium and chromium targets respectively.

Freestanding films were obtained in two different ways:

1. Films that typically present high residual stresses such as TiN and CrN were deposited on flexible AISI 316L stainless steel coupons and peeled off by bending the substrate.

2. Anviloy/Al and H-13/Al films were deposited on glass substrates coated with a thin polymer film that was dissolved after deposition.

The multi-layer films were then reduced to small flakes and placed in alumina crucibles for thermal analysis. In the case of H-13 and Anviloy it is important to note that because the films used in this investigation were obtained by sputtering H-13 and Anviloy targets, the microstructures of the films are not the same as the source materials. Nevertheless, the basic components in each alloy are present in the films and reactions are expected to represent the behavior of the bulk materials.

Results: Caution must be used when comparing results for coatings tested using this technique with actual dies because the test does not consider adhesion, erosion or thermal fatigue tendencies. However, the following conclusions can be drawn:

• This differential thermal analysis technique has demonstrated the ability to detect reactions between die materials and coatings with aluminum and can determine the reaction initiation temperature and the susceptibility to reaction with aluminum.

• With the exception of CrN and Al2O3 all systems tested exhibited exothermic reactions initiating at temperatures below the melting point of aluminum.

• Onset temperatures for the different reactions may be used as a means for comparison and selection of die materials and coatings.

• The formation of an oxide layer on top of Anviloy delays the reaction between aluminum and the die material.

• Results suggest that oxidized Anviloy® 1150 should have soldering resistance superior to H-13 tool steel. CrN should have superior soldering resistance to TiN coatings. Overall, CrN and Al2O3 exhibited the best performance.

Implementation Strategy: The results of this project will be useful for rapid evaluation and comparison of commercial die material, surface treatment and coating systems prior to testing in actual die casting operations. It can also be used for further research into die material, surface treatment, coating system and casting alloy development, but is not practical for die casting companies to use for routine evaluations. ■

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