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Material innovation for die casting molds

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Abstract

Quest for a material to suit service performance is almost as old as the human civilization. Traditional die casting steel mold materials fail due to metal- fatigue cracking, corrosion, erosion, soldering etc when subjected to cyclic mechanical and thermal load. The objective of this work is to find an optimal mold material composition and process parameters for the use in die casting industry using direct metal manufacturing. Design of experiments and Response surface methodologies are used in identifying the coating materials and optimizing the process parameter inorder to develop the innovative coating material. The newly developed coating material is then evaluated for its mechanical and thermal properties. With the newly developed material and process, the production time and the cost is considerably reduced.

Keywords: Process optimization, Direct Metal deposition, Die casting

Introduction

Products and materials are created and enhanced to meet new industry demands. Researches are done at finding the right approach with the right material to build and optimize the product or process line from concept inception through product development. This research is directed to die casting industry. In the die casting industry, the steel dies often fail prematurely due to metal-fatigue cracking, corrosion, erosion, oxidation, heat checking, and soldering when the dies are exposed to molten metals while operating under cyclic-mechanical, thermal loading, chemical corrosion, and thermal fatigue. For many applications, die coatings and surface treatments are used to improve the properties of the dies. The application of coatings via Physical Vapor Deposition(PVD), Thermo-Reactive Deposition or Diffusion, or Chemical Vapor Deposition (CVD) to the molds have shown promising results for increasing wear resistance, reducing die maintenance, and reducing machine downtime. Depending on the applied technique, these processes often fails, due to a high level of porosity, the presence of a heat affected zone, poor bonding of the applied surface to the base material. This may entail a risk of distortion or embrittlement, and often produces toxic and corrosive gases. Laser cladding is a method that could be used to enhance the property by depositing a coating material. The properties of the coating do not depend upon the material alone; they also depend on the laser processing parameters and the composition of the coating powders. The laser processing parameters, material selection, and thermal conductivity of the material are the major factors that influence the property of the coating.

In this study, laser is used as the optical source of energy to deposit the coating material which is made up tungsten and Inconel. The research included selection of the materials, optimizing the materials, and optimization of the process.

Selection of materials: Material Matrix

Die wear and failure are significant issues in die casting. Permanent molds used for die casting aluminum alloys are selected from a wide range of materials ranging from grey iron to high tensile tool steels. The usual mode of failure of permanent molds is Thermal Fatigue Cracking caused by cycle thermal stress on the mold surface. Resistance to thermal fatigue can be increased by using mold materials that have a combination of high thermal conductivity, high strength at elevated temperatures, low coefficient of thermal expansion, and a low modulus of elasticity.

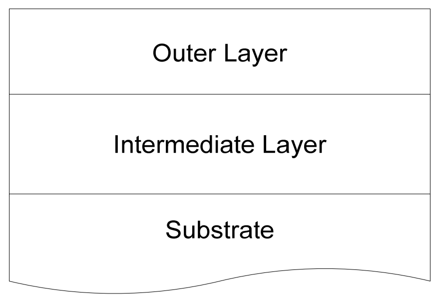

Figure 1: Conceptual design of the mold

The performance criteria, like the wear resistance, soldering, thermal fatigue etc are to be met by the coating. No single coating can provide an optimum system. So a material matrix system is designed for the coating where each coating is for a specific purpose. The outer layer of the mold provides the required wear resistance and non-sticking properties while the inner layer provides good adhesion and thermal conductive properties. So this research would provide a promising material matrix for die casting molds. Figure 1 shows the conceptual design of the mold. The surface alloying of transition-metal elements are often added in high concentration to improve the properties; transition- metal additions account for roughly one-third of the cost of alloyed steels and surface alloying could reduce the usage. Various researches have shown an improvement in properties after implanting tungsten. For improving the tool steel properties for the use as a cutting tool, the H13 steel samples were implanted with tungsten, and showed improved surface mechanical and wear resistant properties. Transition metal carbide materials have a higher hardness, lower chemical reactivity and retain good corrosion resistance at high temperatures, which makes tungsten carbide (WC) suitable for our application as the coating material. Base material is the major part of the composite mold, it helps in removing the hot spots thereby reducing heat checking and soldering and increasing the life of the die. Thermal expansion, adhesive property, hardness, avoiding group 2B materials, and economics were used for the selection of the base material. Based on the above criteria copper chromium was selected to be used as the base material. For the intermediate layer or for the phase changing layer H-13 or Inconel could be used since it this material was already proven to work with copper chromium. The main challenge is with the selection with the coating material, where the molten metals are exposed to cyclic mechanical and thermal loads. The dies often fail prematurely due to the metal fatigue cracking, corrosion, erosion, oxidation, heat checking, and soldering. For most of the applications, coatings are applied to protect the die from the damage caused by molten material. The coating material is the one that is in direct contact with the die casting product. The base material would be a cushion to the coating material in order to enhance the property of the die casting mold by providing good thermal properties. The coating material should be capable of providing sufficient strength and hardness at elevated temperatures, good wear resistant properties, minimum porosity, good bonding property, similar thermal conductivity property, and safe to the environment.

Process parameters

The surface structure can be constructed based on the surface requirement. A variation in any one of the process variables, such as laser beam profile, feeding parameters for powder injection, machining parameter and the material for the application make different configurations. A change in a process parameter makes changes in the microstructure of the laser melt zone. The mastery of this process requires correlation between the treatment parameters and the phenomena induced during the laser material interaction. The main cause effect diagram shown in Figure 2, shows the various process parameters involved with the DMD machine that influence the process results.

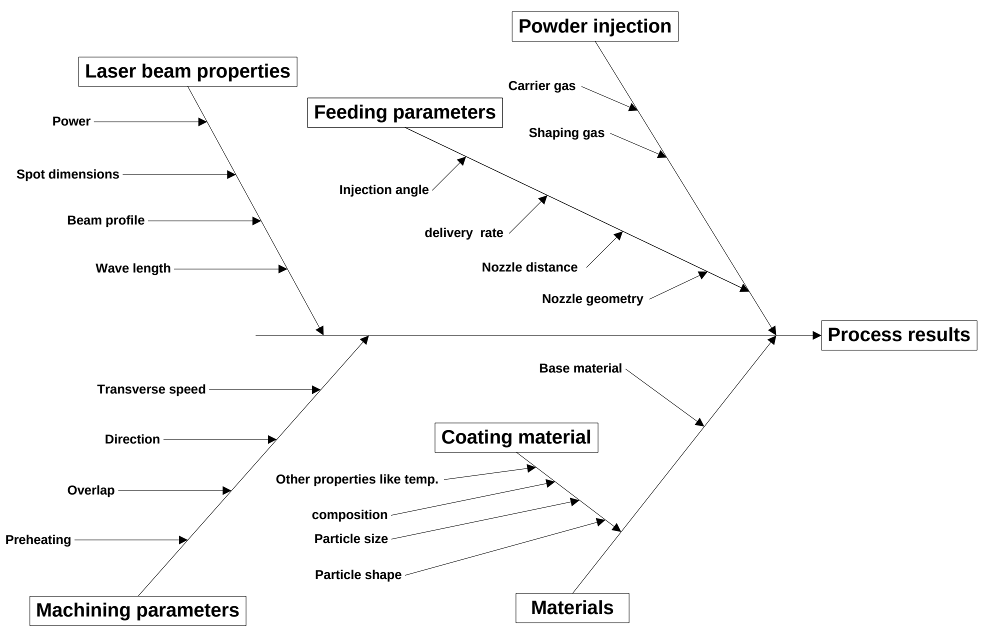

Figure 2: Main cause effect diagram

The most important parameters are selected for a more in depth study and the remaining parameters are held constant. Literature reviews, past researches, and experiments are used to define the least important parameters. The modified cause effect diagram is illustrated in figure 3.

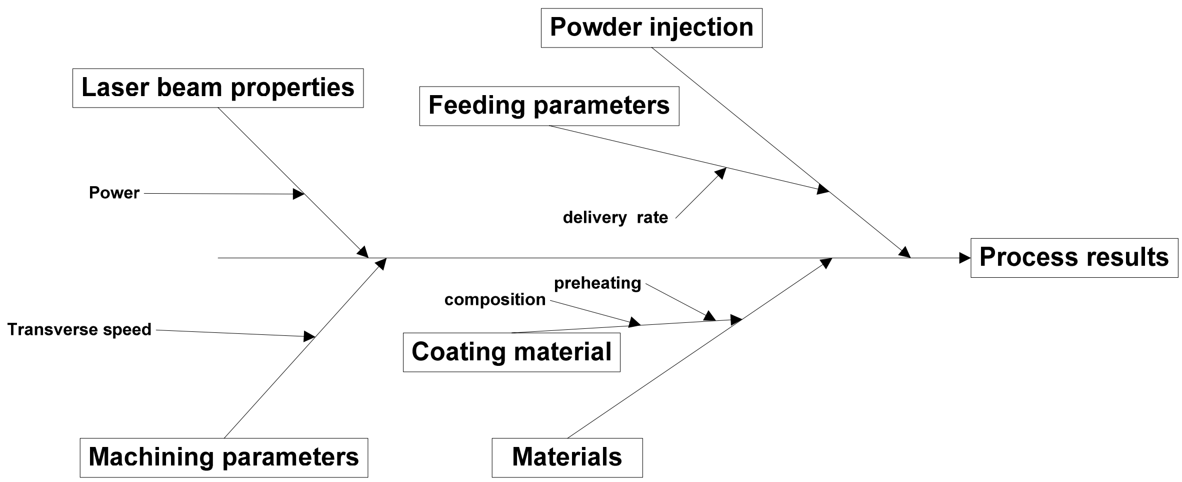

Figure 3: Modified cause effect diagram

Experimental work

The experiments are done on a Direct Metal Deposition (DMD) machine that fabricates final near net-shaped and fully dense metal parts- both thin shell and solids- directly from the CAD solid model without using any of the conventional machining processes. The machine that is used for this research is the DMD 3000 machine equipped with a 3000 watt CO_2 laser as the optical source. The powders of tungsten and Inconel 718 with the nominal composition given on table 1 are used as the coating material. The grain size of the coating powders varied from 30 to 120 micron. The property of the coated material will depend upon the laser processing parameters and composition of the alloying powders. The powders flowed from the nozzle to the melting zone by means of gravity continuously at a desired powder flow rate; magnetic vibrators are used in addition for tungsten flow.

The composition of the tungsten powder was varied form 30% to 50% and balance composition was Inconel 718. The laser parameters were maintained same through out the research, overlapping of the deposition was maintained at 30%. The Micro structural study of the laser passes and the bonding between the substrate material is studied using optical and electronic (scanning electron microscope (SEM)). The abrasiveness of the material is given by its abrasive resistance factor (ARF). The abrasive resistance factor is calculated as per the ASTM G-65 standard. Thermal conductivity of the material shows how fast the material would be able to move out the heat from the system, thermal conductivity was measured using parallel thermal conductance technique.

The coating material was deposited in a biscuit size of 2” x 1” for ten layers, based on the processing parameters the height of the coating material varied. Typically the height of the deposit was between 0.06” to 0.09”. Final machining was done on the deposited samples before any testing was carried out. Deposited samples were sectioned, polished, and etched for the structural investigation by optical and scanning electron microscope.

Results and discussion

Abrasive resistance

The abrasive test method covers laboratory procedures for determining the resistance of metallic materials to scratching abrasion by means of the dry sand/rubber wheel test. It is the intent of this test method to produce data that will reproducibly rank materials in their resistance to scratching abrasion under a specified set of conditions as specified by the ASTM standards. The figure 4 shows the test piece after the abrasive resistance test. Abrasion resistance is an indication of how well a material holds up to rubbing, scratching, gouging, or other forms of friction-induced wear.

Fig 4

Fractional factorial design was used to determine the effect estimate and to find out the significant variables using ANOVA. The significant variables are then used to develop the regression model. Laser power, feed rate, composition of tungsten, and the interaction between the laser power and feed rate are identified as the significant factors identified by ANOVA. The regression equation corresponding to the model is as follows, ARF = 13.6 - 2.43 A + 3.09 B - 2.80 AB + 1.17 C; where A, B, C corresponds to the coded value of laser power, feed rate, and percentage composition of tungsten. ARF was comparable to the material that is used in the industry. Figure 6 shows the comparison between the various materials. No pitting, spalling, or chipping was found after the abrasive test. The laser cladded coating material exhibited better abrasion resistance when compared to Anviloy.

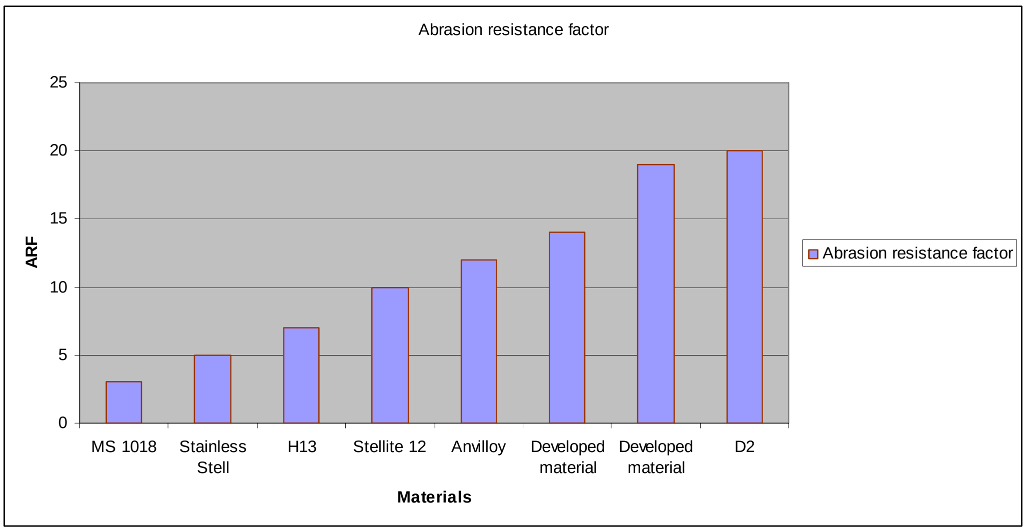

Fig 5

Hardness

Depending on the quality of the deposit, the hardness value varies. Poor deposits will give a lower value because they may generate voids during the process. There are two types of tests by which hardness is measured: macro and micro hardness tests. Macro hardness tests are carried out to determine the resistance of the total coating deposit to point penetration, measured with either the Brinell or Rockwell hardness test. In this research, macro hardness tests are carried out because they would give the overall hardness of the material.

A fractional factorial design was done to analyze the significant factors that are involved with hardness as the response. Regression was determined to be the most common form of statistical analysis. Finding a regression model, and using the model to maximize hardness determine the optimum settings for the operating parameters. MiniTAB regression function was used to find the regression model based on all factors. Since there was only one replicate, the effects output of the fractional factorial design is used to find the variables to be used in ANOVA. The terms in this model was evaluated for relevancy based on their probability values (p-values). Probability values were used to evaluate the significance of a statistical term. The significant variable was identified from the MiniTAB results (p – value). To simplify and provide a more realistic model, interaction terms with low significance was removed. Therefore based on ANOVA the significant variables identified are composition, interaction between laser power and composition, and interaction between feed rate and composition. The detailed analysis is shown in the appendix (page 120 -122).

The regression equation corresponding to hardness is as follows

Hardness (HRC) = 37.8 + 0.825 C + 0.575 AC - 0.575 CB; where A, B, C corresponds to the coded values of laser power, feed rate, and composition.

The high R^2 value measures how well the model fits the data that also considers the number of model parameters and number of data points used in the analysis. The value represents how much of data could be predicted by the model. he settings of the process parameters can be optimized with this model using the coefficients and range of settings for each term.

Conclusions

A new coating material is developed using a powder mixture of tungsten and Inconel 718 via laser cladding process and was deposited successfully with out any cracks or any issues related with porosity. The new material developed has properties profile, which is superior to premium H13 / Anviloy regarding hardness and abrasive resistance. The new material developed presents a promising option for the use of coating material for the die casting industry. The relationship between the various process parameters and the properties were studied.

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Meet the author

Jaby Mohammed received his B.S. in Mechanical Engineering from University of Kerala, India in 1997; he received his MBA with specialization in Operations Management from India in 2001, his M.S. with a concentration in Industrial Engineering from University of Louisville in 2002, and his PhD in Industrial engineering with concentration in advanced manufacturing from University of Louisville in 2006. He is a member of IIE, ASQ, SME, NAIT, POMS, and Informs