MONARCH ALUMINUM MFG. COMPANY

Draft #1

ALUMINUM BONDING RESEARCH PROJECT

This report deals with the experimentation, and research work done in the laboratory in the investigation of methods for bonding of ferrous materials with aluminum alloy. All data presented herein, is the result of actual experimentation made in the laboratory with the apperatus and equipment of the company. All opinions and conclusions contained in this report are those of the author, and have been substantiated wherever possible by direct experimentation. Several items discussed require further work to prove them out under actual operating conditions in the foundry. The basis for this report was to determine if the several possible bonding methods could be accomplished even under laboratory conditions, and to obtain as much technical information as possible as to the advantages or disadvantages of each. It must be pointed out, that in some cases, a method may be satisfactory with a small sample under strict laboratory conditions, yet IT will not be practical under actual foundry operations in production. Much important information has been obtained from this experimentation that could save valuable time in the future if this work was continued in greater detail.

The micrographs and photographs included in this report are taken of the actual samples under consideration and are so marked. All information is included as to method, technique, and results. To avoid confusion as to the several bonding methods referred to in this report they are listed as follows. Metallized sample refers to a ferrous base material coated with sprayed aluminum. ALFIN refers to ferrous material coated in hot dipped molten aluminum and flux. MONARCLAD refers to ferrous base material coated by hot dip methods in zinc or zinc alloy, both with and without the use of flux. The name MONARCLAD was selected to indicate a coating technique different to any previously attempted. Other methods are not listed by name, but by description.

EXPERIMENT 1 - Ultra-sonic excitation. April 9, 1958

The suggestion that a possible bond might be obtained with the use of ultra-sonic excitation in the place of flux or metallization was explored. A clean steel bolt was obtained. After cleaning to remove all oxides and hydrocarbons (Grease oil) no contact with hands or organic materials was permitted. The bolt was pre-heated to a temperature of approximately 400° F. The pre-heat temperature was kept below the zone where visual oxide formation takes place. 43 alloy aluminum was melted in a graphite crucible to 1500° F. (All temperatures were pyrometer measured and controlled) The bolt was attached to the ultra-sonic transducer as indicated in fig. 1.

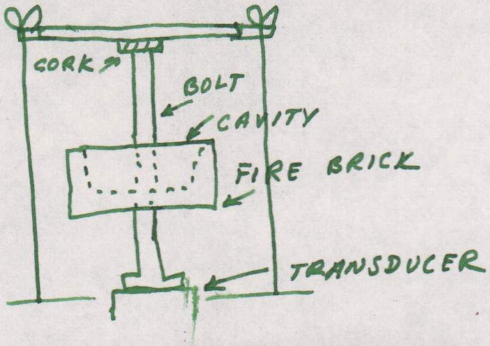


FIG. 1.

Sealing wax was used as the couple medium because of its higher melting temperature. The sample mold was constructed from a section of Silocel insulation brick. This type of mold was used to provide the longest cooling time for the aluminum alloy, so as to allow a long period of ultra-sonic excitation to the sample. The ultra-sonic energy was applied and the aluminum metal poured as quickly as possible. It was noted that as the aluminum was being poured, the resonance of the assembly changed. This may be due to either damping action of the molten aluminum or a thermal expansion of the steel bolt as it absorbed heat from the aluminum. An attempt was made to prevent this expansion by the insertion of a cork spacer at the top of the bolt between the support and the bolt. However, this was not as effective as desired. This change of resonance would present problems in production casting conditions, since it would be impossible to predict the resonance of the system before the sample was poured. The ultra-sonic energy was continued for about one minute until the surface of the molten aluminum started to solidify. The energy was then discontinued and the sample allowed to cool normally. The sample was then sectioned and examined microscopically. There was a definate indication that the aluminum had "wetted" the steel. However, this condition was not continuous around the entire diameter of the bolt. Fig. 2 indicates the intermetallic layer next to the steel. The dark area is void since the aluminum alloy was broken away from the steel intentionally.

FIG. 2
250X

The bolt was then sectioned along its length as indicated from fig. 2. This revealed a coating along part of the surface near the place where the aluminum remained molten longest, (Area of longest ultra-sonic excitation). This condition is illustrated in fig. 3.

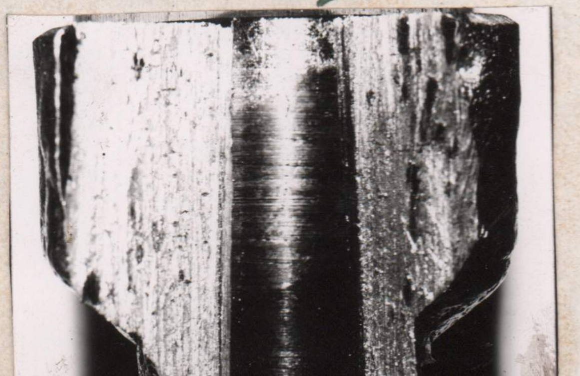


FIG 3
3X

It might be concluded from this sample that an intermetallic layer is formed between tha aluminum and the steel. It can also be noted that this layer has a greater attachment to the steel than to the aluminum. The difficulty in running this type of CASTING method under actual production conditions is great and could not guarantee satisfactory results every time.

EXPERIMENT 2. - Ultra-sonic excitation. April 10, 1958

A second steel bolt was obtained but coated with the metallized aluminum. This bolt after coating, was run through the ceramic Selas furnace in the same manner as all other previous samples. After cooling, it was set up in the exact fashion as the sample in experiment 1. All conditions as to metal alloy, temperature and pouring were identical to the first sample. The same damping conditions were noted as in the previous run. Our problem was to determine if a metallized bolt would provide any advantage over the uncoated one. After sectioning this sample and examination with the miscroscope it was noted that no bonding took place between the aluminum and the metallized layer. A good bond was formed between the metallization and the steel. The sample was then sectioned along its length as in the first experiment. This indicated a discolorization on the surface of the metallized layer, with no attachment of the 43 alloy. This can be seen in fig. 4. This shows there is no attack on the metallized layer from the aluminum alloy. Probably, the oxides on the metallized layer act as an insulator and prevent the alloying of the aluminum. The ultra-sonic energy does not seem to break this oxide layer down. It was also noted in both experiment 1 and 2 that considerable gas was formed in the metal.

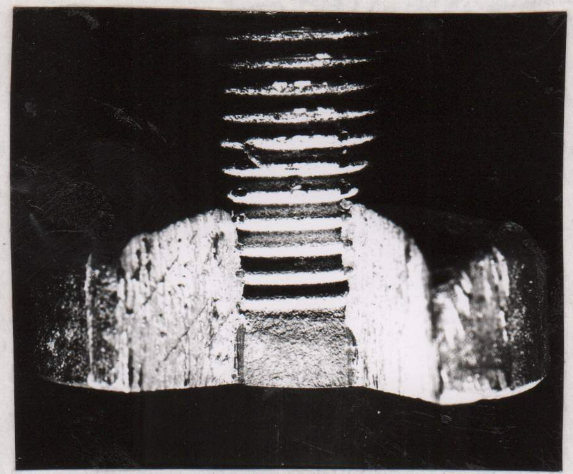


FIG. 4
3X

Much thought was given the problem of oxide removal from the metallized layer. This is the major problem to a satisfactory bond when aluminum is used as the material to form the interface. Pure aluminum, as used in our metallization set up has a melting point very near to that of the aluminum alloy cast around it. Also, the fact that the steel to which the metallization is in contact, tends to draw off heat, all contribute to the difficulty of bringing the metallized aluminum up to a fluid condition. This coupled with the problem of breaking down the insulating oxide layer makes a very difficult casting problem.

It was thought that some other metal might be substituted for the aluminum metallization that had properties more suited to alloying with aluminum. This idea evolved into the MONARCLAD system. Zinc and zinc alloys such as Zamak were considered as substitues. It is well known, that zinc will coat iron base materials with great ease. This is similar to galvanization. There is a definate alloy condition between zinc and iron that starts to form at rather low temperatures. See fig 5. It can be seen that this alloying starts around 980 to 1000° F. (The melting temperature of zinc is around 800° F.) At temperatures of 950 to 1050°, the attack of zinc on iron is very rapid. This condition is in evidence on our pyrometer protection tubes, and even on our zinc melting pots. To prove

IRON - ZINC

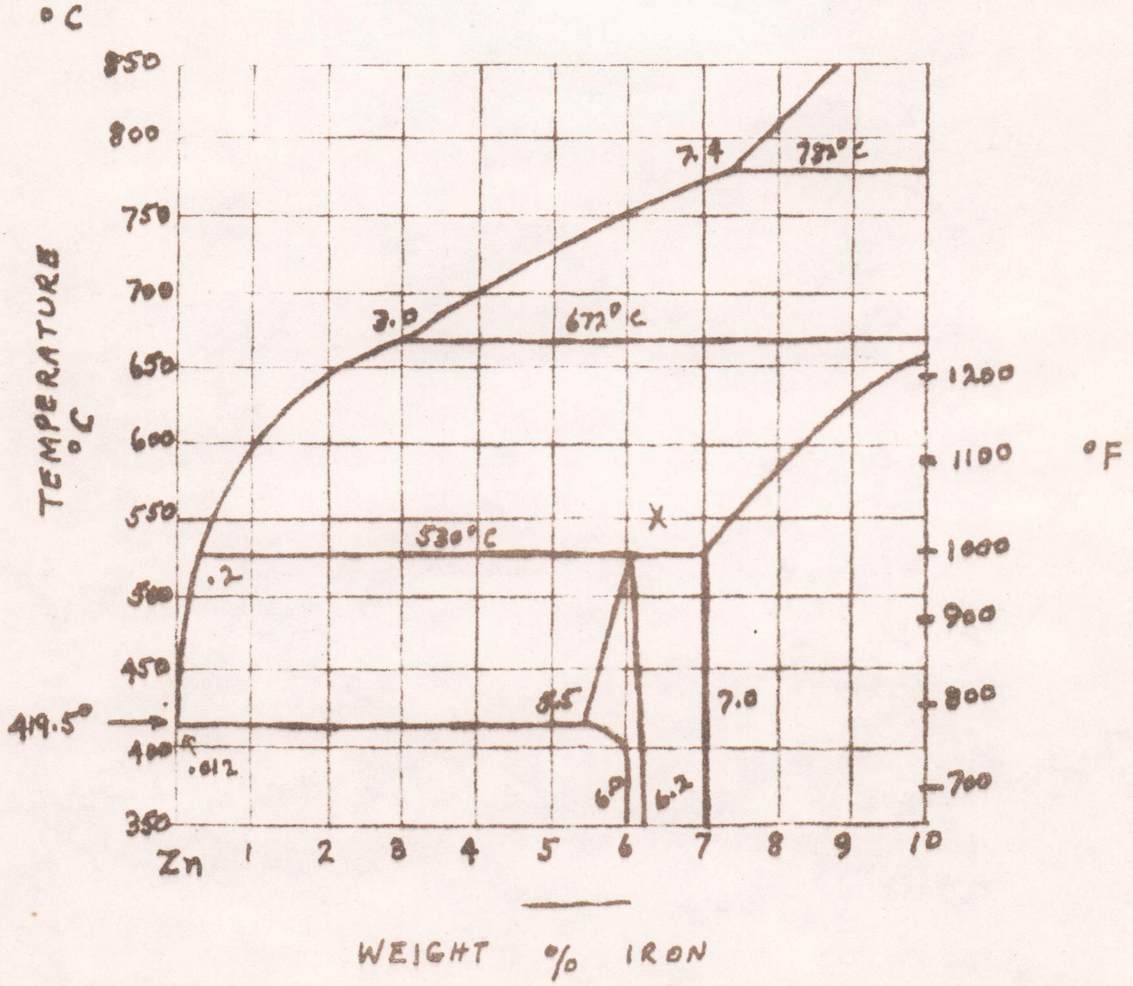


FIG. 5

this out, several common steel nails and steel bolts were subjected to coating of zinc by a hot dip method. The procedure is as follows. Zamak alloy was melted in a crucible to 1000° F. ALCOA #33 braze flux was added to surface of the molten zinc, and the steel nails and bolts were inserted under the surface of the zinc. The entire crucible was agitated and the metal stirred. The steel items were removed one by one and rapidly shaken to remove all excess zinc. The agitation was to assure complete coating of the steel. The steel was left in the molten zinc for several minutes. The small amount of flux that adhered to the surface of the coated steel was removed by immersion in water since the flux is a water soluable type. Several of the steel samples were left with a thick coating of zinc to determine if a thick or thin coating had the better bonding properties. The coating of steel without the use of any type of flux was also tried. It is possible to coat a steel sample with zamak without flux. However, the steel must be very clean and must be in the molten zinc for a longer period of time. The actual bonding is the same if flux is used or not. The only advantage of flux is that the steel is processed more rapidly. The particular use of ALCOA #33 flux provides only one advantage. The flux has a melting temperature of about 1000° F., and does not decompose rapidly in zinc. This flux was intended by ALCOA for use as a braze flux for aluminum. However, any good flux such as ammonium chloride, zinc chloride or even sodium potassium chloride mixtures or any combination of these will be just as satisfactory. The soldering type low melting fluxes can also be used, rozin, ammonium chloride/ zinc chloride, but these have a tendency to react with the zinc since they are used for cleaning zinc metal and will produce dross that has to be removed from time to time. A organic flux might also be considered for this application. All the above mentioned flux material was tried, with the exception of rozin and all worked about the same.

FIG. 6
25X

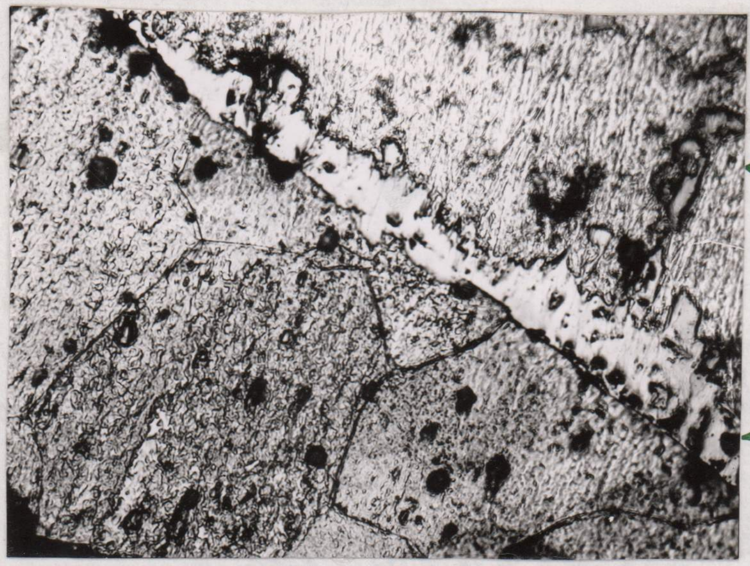


FIG. 7
250X

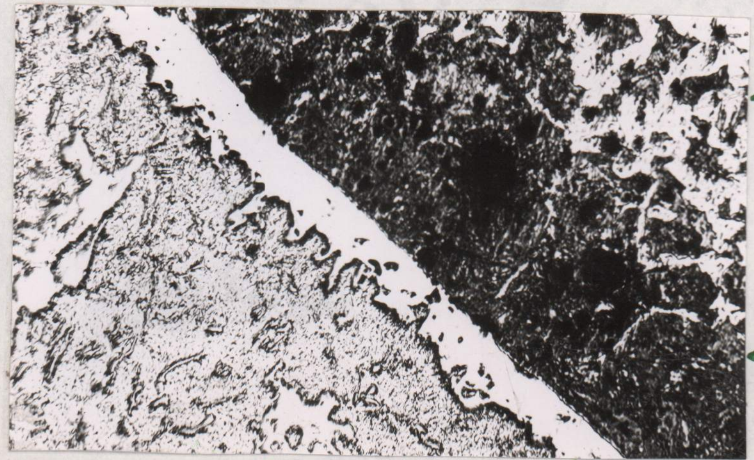


FIG. 8
250X

and then rapidly quenched in cold water. This cycle was done over and over for about an hour. At the end of the test, no change in the smmple could be detected other than a heavy oxide on the exposed steel surfaces. No detachment of the steel from either the bonding layer or the aluminum cast around it could be detected. The temperature was then raised to 1000° F. and the heat/quench operation repeated. This was done for the same time in 5 minute cycles. Again, no deterioration of the sample could be seen. It could be assumed from this test that the bond is satisfactory as to thermal changes.

A similar sample was then selected and cast in a permanent mold under the same conditions. Sectioning indicated that the same excellent bonding conditions were apparent in the PM sample as the fire brick mold. It can then be concluded that cooling rate has very little importance on the bonding conditions.

EXPERIMENT 4 - Monarclad steel - April 14, 1958

One of the steel bolts that had been coated with a rather heavy coating of zinc was selected and pre-heated to approximately 600° F. This bolt was then inserted into a hot permanent mold and cast in 319 alloy at a pouring temperature of 1250° F. The sample was allowed to cool to room temperature, removed, sectioned and examined. It was noted that the intermetallic layer was formed as in previous samples, but it was much thicker and was not as "solid"looking as previous samples. Free zinc was also present between the aluminum and the interface. It would seem from the sample surface that too thick a coating is not satisfactory. The excess zinc does not alloy to completion before the aluminum solidifies. This condition allows for weak sections in the casting. It can be concluded that too thick or too thin a coating is unsatisfactory. A coating about the thickness of our metallizing is best. Thick coatings also tend to break away from the steel surface because of the high brittleness of the zinc/iron layer. Too thin a layer seems to retard complete bonding or alloying. Some areas in this sample are free of adherence to both the steel and the aluminum.

Several Monarclad steel samples were cast in different alloys to see if they were compatable. In all cases a satisfactory bond and interface was produced. Several items are noted as to good and bad practice. Excess zinc is to be avoided. The zinc temperature should not be below 900° F. and not over 1020° F. Immersion time in the zinc should be about 5 minutes. Too long an immersion time will cause attack on the steel part. Too little a time will cause poor adherence to the steel. Temperatures over 1020° causes oxidation of the zinc and requires more flux for the same coating condition. The mold must be hot before the casting is poured. The metal (alumihum) temperature must be hot, over 1200° F. Temperatures up to 1700° F. were tried with no improvement over the normal casting range. Agitation of the mold or the molten aluminum helps produce a good casting. The agitation helps remove any dross, oxide, or gas that might be formed during the pouring. The coated steel insert should be pre-heated. This pre-heat temperature may be as high as 1000° F. There was no optimum temperature found where bonding was best. This is dependent to some extent oh the physical size of the steel insert and its total area in contact with the molten aluminum.

EXPERIMENT 5 - MONARCLAD CAST IRON (Brake drum) - April 15, 1958

After satisfactory results were obtained with steel samples, it was decided to investigate the properties of cast iron as to bonding and casting. Sections of cast iron brake drum were obtained and attempted to coat with zinc. It was noted at once that difficulty was experienced trying to "wet" the cast iron with the molten zinc. Only sporatic areas of the cast iron alloyed with the zinc even though large quantities of flux was used with the zinc. Both flux covers on the zinc and flux coating of the cast iron was not satisfactory. Various temperatures were tried to seeif this was a factor but no satisfactory results could be obtained. It was noted that during the coating operation and even in the pre-heating operations that a black coating formed on the surface of the cast iron. This condition is inherent to cast iron and starts to form about 800° F. This is one of the principal advantages to the use of cast iron in brake drum service. Since cast iron has a great deal of free carbon in the form of graphite, (Up to 2 or 3 %) it provides good antifriction surface which is required in a brake drum or other metal to metal surface where no lubrication can be used. This free graphite on the other hand prevents the adherence of molten metal and thereby prevents bonding or alloying with the iron itself. Since this condition starts to form at a rather low temperature and cannot be removed from the surface of the metal, great difficulty is experienced in forming a clad surface. To examine this further several brake drum sections were metallized and examined. In all cases but one, no bond was formed at the surface of the iron and the aluminum metallization. Considerable carbon was noted near the surface of the cast iron. The one case where a bond was formed with cast iron, was that of no "curing" operation on the metallized iron. This sample was metallized and directly inserted into the mold and cast. No pre-heating of any kind. It should be mentioned, that the sample under investigation was very small and a large quantity of molten aluminum was poured around it. It prabably did not have enough time for the graphite to form on the surface of the iron before the alloying started with the metallized coating. Working on this assumption, several other clean cast iron samples were insertedinto molten zinc at 750° F. and REMOVED ~~then raised~~, the graphite DID ~~does~~ not form as quickly. If very hot temperatures are used, over 1000° F., and a cold iron sample is inserted the same condition takes place. This was the only way any kind of bond was able to be made. Flux must also be used to obtain this condition. Several other cast iron samples were obtained from the tool room. These samples were treated with both zinc coatings and with the usual metallized aluminum. The metallized samples were both "Cured" in the Selas furnace and left as metallized. The samples were then inserted into molds and molten aluminum alloy poured around them. In all cases, no bond was formed. A steel sample, of the same size was treated the same as the cast iron and run through the identical operations. In all cases a bond or intermetallic layer was formed on the steel. It could be concluded from this work that the formation of a bond with cast iron of the type used for brake drums is quite difficult. The reason being the high carbon concentration. There may be a possibility of metallizing the cast iron with a silicon steel and aluminum metallizing over the steel coating. However, this represents considerable handling and cost. It would be better to construct the brake drum from a low carbon cast iron or from a low alloy steel.

EXPERIMENT 6 - CAST IRON MONARCLAD ALUMINUM CAST - April 17, 1958

Since it has been mentioned that cast iron may be coated with zinc if special controls are followed, it eas decided to coat a brake drum sample and attempt to produce a casting similar to that encountered in an actual foundry set up. A one inch section of brake drum was selected and cleaned. This section was then immersed into molten zamak at 800° F. The surface of the molten zinc was covered with ALCOA #33 flux. The cast iron section remained in the zinc alloy and the temperature brought up to 1020° F. This operation took approximately 10 minutes. At the end of the 10 minute period the sample was removed from the zinc and allowed to cool. No attempt was made to remove any of the excess zinc from the surface of the cast iron. After cooling to about 300° F. the coated cast iron was placed into a cavity cut into a fire brick mold similar to experiments number 1 and 2. 319 aluminum was heated to 1600° F. and cleaned to remove all oxides from the surface of the metal. The aluminum alloy was poured into the mold and allowed to cool. The conditions of the mold were such that cooling of the metal was very slow. The reason for selecting a very long cooling time was to determine if prolonged contact of the hot molten aluminum would remove the bonding layer from the surface of the cast iron. In this experiment it was thought that flux would aid in the alloying of the aluminum to the zinc, so that considerable flux remained on the surface of the zinc coated cast iron. After cooling the sample was removed from the mold and the surface (End) sectioned. It was noted at once that there was a hard bright layer between the cast iron and the aluminum. It was also noted that there was considerable gas present in the casting, probably due to the excess flux used, and that there were small inclusions scattered over the entire area of the aluminum but greater in concentration near the coated surface of the cast iron. These inclusions had the appearence of being the same as the layer next to the cast iron itself. Microscopic examination indicated a bond between the aluminum and the cast iron. This layer was uneven and very hard. The inclusions had the same appearence as the interface layer and were assumed to be the same composition. No free zinc could be found anywhere over the surface of the casting. The visual section of this casting may be seen in fig. 9, and the microscopic view in fig. 10. The voids contained traces of flux crystals.

CAST IRON BRAKE DRUM INSERT

FIG. 9
5X

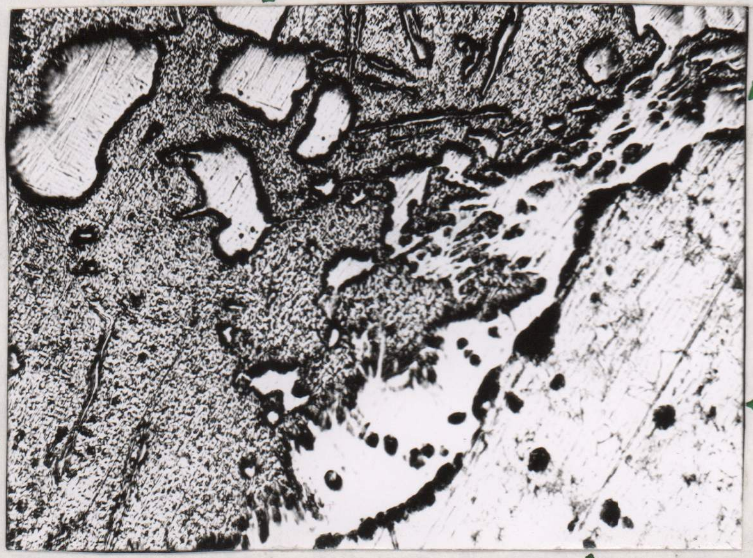


FIG. 10
250X

The sample was then sectioned along its length and struck with a hammer to remove the cut aluminum. Again, several hard blows were required to remove the aluminum and the broken surface of the cast iron indicated a tearing away of the aluminum from the iron. It would be concluded that a definate bond was formed between the cast iron and the aluminum. It could also be concluded that very high metal temperatures are not ~~required~~ DESIRED ~~[illegible]~~ , AS WELL AS, prolonged cooling time. Excess flux is to be avoided as much as possible. After several days, it was noted that the flux caused corrosion to the cast iron. Any flux imbeded in the metal in contact with moisture will cause this corrosive condition and should be avoided.

EXPERIMENT 7 - CAST IRON BRAKE DRUM SAMPLE MONARCLAD - April 21, 1958

On the basis of the results obtained in the previous experiment, it was decided to again try to cast a brake drum section. A permanent mold was used in this experiment. The cast iron treated on one surface only, with the metal cast on that surface. This was to duplicate as much as possible the actual working type of casting that would be encountered. A brake drum section was cleaned and coated as in the previous experiment. However, the cast iron, upon removal from the molten zamak, was shaken rapidly to remove all excess zinc and flux. A lesser amount of flux was used, just enough to keep the surface of the zinc clean and liquid. A light film of flux was placed over the surface of the cast iron. This was applied wet and allowed to dry and the cast iron placed in the muffle furnace. The temperature of the furnace was brought up to 600° F. The cast iron section was then removed and placed in a pre-heated permanent mold. 319 aluminum alloy was melted to 1300° F. and poured into the mold. After cooling the sample was removed and sectioned. It was noted that this sample was an improvement over the first. No gas or inclusions could be seen to the naked eye.

A distint layer could be seen next to the cast iron. See fig. 11. Microscopic examination indicated that a bond was formed, but this bond had several cracks or pockets along its length. The band visible along the entire length of the cast iron surface in fig. 11, was probably a layer of zinc/aluminum alloy. This can be seen in fig. 12.

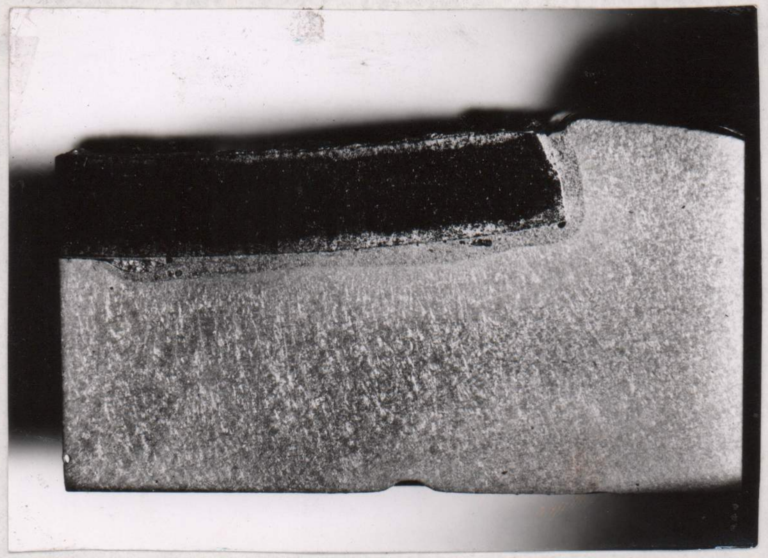


FIG. 11 - 5X

The cast iron was very adherent to the aluminum around it, and gave the same properties as before. Several blows were required to seperate the cast iron from the aluminum. We are unable to explain the cause for the seperation and inclusions along the surface of the cast iron. It may be possible that this was caused by the flux layer on the coated iron, or unequal thermal expansion between the cast iron and the coating. Several other sections of cast iron were obtained and cast. Both with Monarclad zinc and metallized with aluminum. The only success was with the zinc coated types and these were not too satisfactory. The problem is with the flux, too much is bad, poor bonding and not enough will cause coating of the cast iron with graphite. Considerable work will be required on this problem before satisfactory results can be obtained.

FIG. 12
250X

EXPERIMENT 8 - PLATED BONDING * CADMIUM - April 23, 1958

The possibility of providing a bond by the use of a surface on steel other than a hot dip was considered. Since steel or iron must be chemically clean before plating, it could be assumed that the surface directly under the plate would have the correct charicteristics for bonding. It is also known that Cadmium, used widely for plating on steel has a rather low boiling point, (1400°F.). It then serves, that if a plated steel sample (Cadmium Plate) is placed in a mold and molten aluminum alloy poured around it, the Cadmium plate should boil off at 1400°F. or higher, under the surface of the molten aluminum ALLOWING THE ALUMINUM to form an alloy bond with the steel surface. The boiled Cadmium, (In a vapor state for the most part), should arrive at the surface of the molten aluminum in the form of dross. This can be removed by skimming, if required. However, since the plated Cadmium is very thin it should not be a dross problem. Also, as the Cadmium is boiled from the surface of the steel, the molten aluminum should make instant contact with the steel surface. Since the molten aluminum protects the surface of the steel from air as it forms an alloy, no oxides should form on the steel.

Unfortunatly, only one Cadmium plated rod was available for experimentation. It would have been an advantage to have at disposal a Cadmium plated cast iron sample to experiment with. The Cadmium plated steel rod was pre-heated to about 500° F. (This temperature was estimated). A pre-heated perminent mold was used, and the rod placed at the bottom of the mold. 319 alloy at 1350° F was rapidly poured into the mold. The sample was cooled, sectioned and examined. Fig. 13 indicates the condition of the bond. A definate bond can be seen along some of the length of the steel rod. However, there are areas where the Cadmium plate was not completely removed, probably because of the lower temperature used in casting. In fact, there is a pronounced departure line where the plate was not removed. Since no other plated sample was available, this experiment could not be further pursued. It would seem form the above work that this method has some very definate possibilities, but requires more work to determine correct and optimum temperatures and casting conditions. This is one of the simplest systems devised for formation of a bond, since no flux or surface preperation is required other than the Cadmium plating. This may also be the key to the graphite problem in cast iron.

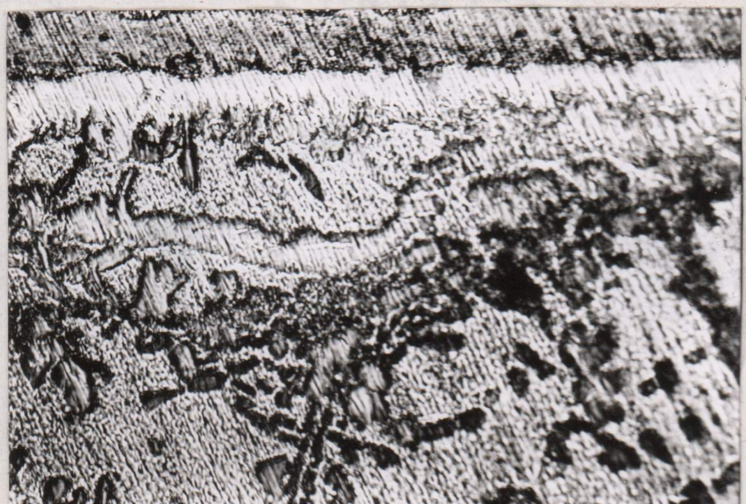


FIG. 13
250X

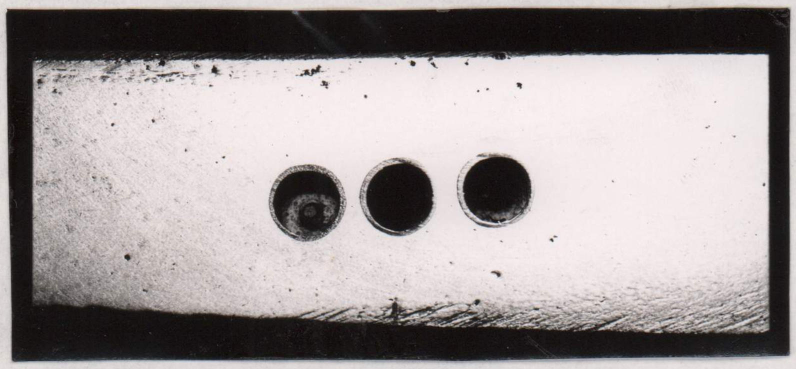
EXPERIMENT 9 Cal Rod Castings, - April 28, 1958

A further experiment was carried out to determine the results of actual casting conditions. It has been established that MONARCLAD surface of zinc on Steel is satisfactory as to bonding and alloying. While results on cast iron were not as successful as desired, the possibility of steel applications should be investigated. One of the current casting problems has been with the Dominion 1006 cal rod casting used in coffee makers. This particular casting is prone to produce voids and blow holes around the tightly coiled cal rod windings. It was thought that if the cal rod used in this casting were MONARCLAD, it would present a more satisfactory surface for alloying to the aluminum poured around it. Also would provide for better heat conductivity preventing hot spots on the cal rod itself, as well as, faster heating time of the casting. If the results were satisfactory in this experiment, it might be considered for other similar applications. The Dominion 1006 cal rod is small, allowing for easier casting in the laboratory.

Cal rods are formed from sheet steel and present a very excellent surface for hot dip zinc coating. Three clean cal rods were obtained from the foundry. These cal rods were removed from the supply in use at the production mold. Two of these cal rods were MONARCLAD by the same method as in the previous experiments. No trouble was experienced in providing a good coating on the steel. Very little flux was used on the surface of the molten zinc, and the excess zinc was removed by rapid shaking of the cal rod. It was apperent that the cal rod surface is very compatable to this process. One cal rod was left un-coated. The cal rods were then cast, in order in 319 aluminum alloy, at a temperature of 1300°F. The un-coated cal rod was pre-heated to a red heat in the same manner as used in the foundry. This was marked as casting # 1. The

This pre heated cal rod was placed into a flat mold, and the 319 alloy was rapidly poured into the mold. (The mold was also pre-heated before the casting was poured). The sample was cooled and removed. The second calrod was then pre-heated to a lower temperature (Approximately 800° F.). The pre-heated calrod was inserted into the same mold in the same position as sample #1. 319 alloy was again poured at the same temperature under the same conditions and technique as No. 1. It was noted that when sample #2 was poured, the aluminum alloy "wetted" the surface of the calrod as soon as it made contact with the calrod. The sample was allowed to cool and removed from the mold. The calrod (coated) for the third sample was pre-heated in a different manner. This calrod was immersed into the molten 319 alloy for about one minute. After removal, it was placed into the mold in the same manner as the first two calrods. The 319 alloy was then poured, sample allowed to cool and removed. The first sample with the uncoated calrod indicated a mechanical bond rather than an alloy bond. The samples #2 and #3 looked alike to visual inspection. It will be noted, that in all three samples only ½ the calrod was immersed into the casting. This was intentional so that the temperature of the calrod itself could be measured under actual operating conditions. The three castings were then connected to power and the heating cycle checked. All three castings were in operation. The uncoated #1 sample calrod came up to a red heat on the uncast section in a matter of two minutes. Sample 2 and 3 did not show red heat even after 5 minutes of operation. The calrod surface temperature in the Monarclad samples were about 100° lower than the uncoated #1 sample. The castings were then measured in the same spot on each casting and it was found that both sample #2 and sample #3 heated the aluminum byabout 30 % faster time than the sample #1.

Unfortunatly, the calrod in sample #3 developed a short, and burned out. This was probably due to the excessive haeting time, since no thermostat was used on any of the castings. In all cases the power was applied directly to the calrods. Samples # 2 and # 3 were then sectioned to examine the interior bonding to the calrod. Fig. 14 indicates the condition of filling of 319 completely around the coated calrod, with no visible voids. Microscopic examination indicated an excellent intermeallic bond as well.



CROSS SECTION THROUGH CASTING

FIG. 14
2X

It could be concluded from this experiment that there is a very good possibilty for the use of MONARCLAD on steel calrods. However, much further work would have to be done on this phase to determine all the probables and variables that might be encountered.

CONCLUSION

No further work has been done on the matter of bonding of aluminum. The material outlined in this report in many cases is only a bare start or exploritory investigation. No sure conclusions were obtained as to actual foundry conditions or problems. Since this experimentation requires much work and time application, much of the work was left unfinished because of lack of time due to other laboratory requirements. However, it has been my desire to explore this problem even if on a limited scale. I feel that the two weeks or so devoted to this experiment has answered many questions about the problems that could not be obtained in any other way. Since very little can be found in technical writings on this subject, a person interested in the problem must establish a research program to discover the answers for himself. We now know, from the results of this project, that cast iron will present problems as to a satisfactory bond with either zinc or aluminum coating because of carbon. We also know that the application of hot dip zinc or zinc alloy will form a alloy bond with steel. Bonding can be carried out with or without the use of flux, and we also know smmething about the temperatures required for the various operations. It is also felt that this information by itself, or later elaborated upon, may be of use in the future for some particular problem or application that might come up. In any event, if these methods were required in the future, much preliminary work could be avoided from the data we now have on hand.

The author is indebted to the personnel in the laboratory for assistance on the various phases of this project as well as helpful suggestions and criticizems.

A. A. Panzer

A. A. Panzer

5/7/58