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ALUMINUM CASTING PROCESS

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6 Claims. (Cl. 22—204)

This invention relates to a process for forming composite or duplex metal structures, specifically aluminum-ferrous metal structures by casting a layer of hot molten aluminum or its alloys to a preformed ferrous metal body or base such as of steel or iron and forming an integral alloy bond therewith. This application is a division of our copending application Serial No. 344,190 filed March 23, 1953, now Patent No. 2,881,491, granted April 14, 1959.

More particularly, our invention relates to such a process in which a fused flux of suitable salts and of such viscosity as to possess ease or freedom of flow, that is to say, a liquid or fluent flux, is employed to effect the alloy bonding of the aluminum with the ferrous metal.

The casting of aluminum to ferrous metal in a mold presents problems not encountered in the conventional aluminum coating procedures where a flux-treated ferrous member is immersed in a bath of the hot molten aluminum to form a coating or predetermined layer of the latter thereon. In the mold casting process, the ferrous member instead of being immersed in a large mass of constantly heated molten aluminum, is placed in a suitable mold into which molten aluminum ladled from the furnace is poured. A heavy cast layer of aluminum of substantial thickness is formed integral with the ferrous metal body and is of a thickness many times that obtained by coating steel with aluminum by immersion or dipping. Necessarily a loss of heat occurs on transfer, and a longer time interval transpires in the casting process during which the flux may cool before the aluminum reaches the flux-treated ferrous metal and fills the mold. Problems of heat exchange, therefore, arise which are not usual in a coating procedure. Moreover, in a dip coating process, if a suitable ductile alloy layer is to be obtained with the ferrous metal, the molten aluminum where prepared from substantially pure ingot, must usually be employed at a temperature immediately above its melting point (1220° F.). In a mold casting process, in order to secure an alloy bond, the temperature of the molten aluminum must be considerably higher than its melting point and higher than the temperatures usually used in a dip coating process. We have found that this feature makes possible a greater latitude in the temperature of the aluminum in operation.

Furthermore, it has heretofore been proposed to cast aluminum to a ferrous metal body in a mold by a procedure wherein the ferrous body is first given a hot dip or flash coating of the aluminum. According to this process, the ferrous body is first dipped in a bath of molten aluminum and then transferred to a mold into which molten aluminum of the bath is then poured so that it contacts the flash-coated surface to form an alloy bond with the ferrous body.

The described process is at best only partially successful and has a number of disadvantages. Unless the interior surfaces of the member are masked with a suitable

graphite wash to protect them from the aluminum bath they will alloy with the aluminum and leave undesired aluminum surfaces that will have to be subseqently machined off. Also oxidized areas form upon the ferrous metal surfaces during heating of the ferrous body when it is immersed in the aluminum bath. The molten aluminum does not wet the ferrous surfaces in the oxidized areas, this even when the surfaces are scraped to break through the oxide layers, and as a result no alloy bond is obtainable between the cast aluminum and ferrous surfaces in these unwetted areas. Stated otherwise, it is difficult by the recited process to obtain a continuous aluminum flash coating, and the cast layer of aluminum subsequently formed is not always provided with a continuous alloy bond with the ferrous metal. Moreover, during flash coating of the ferrous body, the molten aluminum of the bath dissolves some of the ferrous metal. This causes particles of a hard high melting point iron aluminum alloy to accumulate in the bath. In order to settle out these particles, the bath must be allowed to stand. This requires a holding period making extra furnace capacity necessary. If the particles are not permitted to settle out, they may be carried with the molten aluminum of the bath to the molds when it is subsequently poured to make the cast layers. There they form hard spots which make machining of the cast layer difficult.

In seeking a more suitable procedure for successfully casting aluminum or its alloys to ferrous metal bodies in a mold, other methods were considered and it was found that a continuous alloy bond between the cast aluminum and ferrous metal may be obtained by a process utilizing a fluent fused flux composition. It was noted, however, that certain ingredients are essential to the composition and that proper proportions thereof, the temperature conditions under which the composition is employed, and the time interval between removal of the ferrous body from the flux and the start of pouring of the molten aluminum are of a critical nature and necessary of careful control in order to obtain good wetting properties and an acceptable continuous alloy bond between the aluminum and the ferrous metal.

For example, careful selection of the character of the flux composition and of the operating temperatures is essential to avoid thin spots in the protective flux layer or more extensive incomplete wetting of the ferrous metal surfaces, either of which will permit oxidation of the ferrous metal. Moreover, if the flux is too viscous, an excessive amount will adhere to the ferrous surface and may not be easily washed out by the molten aluminum during casting. If the flux is not completely washed off, any remainders are likely to produce unbonded spots between the aluminum and steel which will also be subject to subsequent corrosion. Improper temperature control of the operations, improper compositions, and too long a time interval between fluxing and pouring also contribute to solidification of the flux on the steel before pouring of the aluminum takes place. Where this occurs, the flux adheres to the ferrous metal surface with considerable adhesion and must be melted by the aluminum before it can be washed off. This is unlikely to be complete.

Accordingly, it is an object of our invention to provide a process for casting aluminum to ferrous metal bodies in a mold which utilizes a fused flux composition that provides good wetting properties relative to the ferrous metal surfaces to which the aluminum is to be alloy bonded and which will provide a layer of the flux of sufficient thickness to completely blanket these surfaces to effectively protect them from oxidation prior to pouring of the aluminum.

Another object is to provide such a process in which the ferrous metal surfaces to which aluminum is to be directly bonded by casting are given a layer of fluent

fused flux composition of sufficient viscosity to be adherent and that will maintain its freely flowable character prior to and during pouring of the molten aluminum such that the latter can push the flux ahead of it, i.e. float the flux on top of it without leaving flux remainders as its level changes in the mold.

A further object is to provide such a process wherein the poured molten aluminum will completely wet and cover the ferrous metal surfaces as it removes the flux, and form a complete and continuous alloy bond therewith.

An additional object is to provide fused flux compositions operable in the aforesaid processes.

Another object is to provide a control system for compensating for loss of essential ingredients during operations.

Other objects will become apparent from the following description of the preferred embodiments of our invention. For the purpose of illustration only, we will describe our invention as applied to casting collars or muffs of aluminum on steel sleeves, and in particular to the making of forged alloy steel barrels with an aluminum muff which is to be subsequently machined to provide cooling fins for these barrels which are to form the cylinders in air-cooled tank engines.

In carrying out our invention, we have discovered that the esssential basic ingredients of the fused flux composition are sodium chloride (NaCl), potassium chloride (KCl), and natural Greenland cryolite (sodium aluminum fluoride — Na_3AlF_6). When used in proper amounts, these salts make possible a flux composition having excellent fluxing properties. To these should preferably be added anhydrous zinc chloride ($ZnCl_2$), which we have discovered considerably improves the mixture by increasing its viscosity. Other alkali salts such as calcium chloride ($CaCl_2$) or other fluorides such as synthetic or reduction grade cryolite may optionally be included by addition or substitution but in limited amounts as will be hereinafter evident.

Broadly speaking, by our process, the ferrous metal members after initial treatment by known or hereinafter described procedures to insure that their surfaces are clean and free from impurities, are immersed in a hot fluent fused flux bath (940°–1180° F. melting point) having a temperature preferably substantially not less than 1340° F. and preferably not exceeding substantially 1450° F.

The amount of the essential ingredients to use may vary within certain permissible limits depending upon the character of parts being treated and the time elapsing between fluxing and start of pouring of the aluminum. For example, in some operations especially where the parts to be treated have a relatively small surface area and can be rapidly processed between flux treatment and casting, for example within 30 seconds, the bath may contain a molten mixture of the following essential ingredients in about the amounts stated:

	Parts by weight
Sodium chloride	7 to 40
Potassium chloride	24 to 44
Natural Greenland cryolite	9 to 25
Zinc chloride	0 to 34

Although no zinc chloride has been been used with success in certain compositions, it is generally found expedient to use at least a small amount of this ingredient for its viscosity control feature. However, if the amount of zinc chloride exceeds about 25% by weight, excessive fuming may occur at the higher temperatures and must be controlled. Moreover, cryolite above 25% causes excessive sludging.

Where the ferrous metal surfaces to be treated are large and are not ideal for bonding, or where a greater time period is required, for instance up to about 40 seconds, between fluxing and casting, a somewhat closer range of ingredients is desirable. In such cases the following range of essential ingredients will be found to be preferable:

	Parts by weights
Sodium chloride	25 to 40
Potassium chloride	25 to 40
Natural Greenland cryolite	9 to 25
Zinc chloride	10 to 30

The parts are preferably kept immersed in the flux bath at least until they attain a temperature about that of the bath temperature and are then removed. Such time of immersion is sufficient to provide a substantial layer of the fluent flux on the sleeves or barrels, and to re-melt the initial solid flux envelope which forms on the sleeves or barrels when initially immersed. The actual time of immersion will, of course, vary with the size and composition of the flux bath, and the size and physical character of the ferrous member to be treated and the temperature drop, if any, of the bath. If the sleeves or barrels have been previously hardened and tempered to a specified degree of hardness, it is preferred that the immersion time be kept to a minimum in order to maintain the hardness value close to the original hardness of the member at the conclusion of the casting operation. It has been found that in commercial practice using large flux baths and treating large heat treated barrels of approximately 3/16" wall thickness, about 3 to 4 minutes (usually about 3½ minutes) in the flux bath is sufficient for adequate flux treatment.

When treated in the foregoing manner, the ferrous sleeves or barrels will have a layer of fluent flux composition of sufficient thickness to enable then when placed immediately after fluxing in molds into which molten aluminum (1220° F. melting point) at a temperature substantially between 1325° F. and 1425° F. and preferably between 1350° F. and 1400° F. is poured, to obtain a good alloy bond between the ferrous metal surfaces and the aluminum when the latter is solidified.

The time interval between removal of the flux-coated sleeves from the flux bath and start of pouring of the molten aluminum is also essential of control. In general, the time interval should be short enough to avoid cooling down of the sleeve to a point where substantial freezing or solidification of the flux takes place, or stated otherwise, to a condition where the flux on the sleeve is no longer of fluent character or cannot be rendered fluent on contact with the molten aluminum. In general, it has been found that an interval less than 40 seconds is preferred for best results.

The low temperature limit of the flux bath given above is very important to control in order to avoid an incomplete bond, for example, by solidification of the molten aluminum on contact with the ferrous metal following completion of the fluxing step and contacting of the ferrous member in the mold by the molten aluminum. If the temperature of the flux bath is substantially below about 1340°, for instance 1300°–1320° F., prior to immersion, solidification on contact can occur to prevent a good alloy bond between the ferrous metal and the cast aluminum. For example, this may be the case where proper allowance is not made for a drop in the temperature of the bath due to immersing a cold barrel and bringing it up to the lowered bath temperature and which drop in the case of small baths may be between 50° F. to 75° or where there is a substantial drop in the temperature of the barrel due to too long an interval between dipping and pouring. Moreover, the lower temperature of the flux may decrease the viscosity of the flux film to a point where it is not readily washed away by the rising level of aluminum on pouring into the mold, thus presenting a barrier between the aluminum and steel at the interface. Some deviation below 1340° F., to a temperature in the order of 1300° F. can be tolerated,

for example, in the case of large furnaces (600 lbs.) where little drop occurs or if the elapsed time between removing the ferrous body from the flux bath and pouring of the molten aluminum is made an absolute minimum, for instance, between about 10 to 15 seconds by fast handling of the parts and mold and rapid pouring of the aluminum, or even as low as 1250° F. when an aluminum alloy is employed as hereinafter described.

The upper limit temperature of the flux bath is also critical. If the temperature is too high, the resultant flux will be too fluent and the blanket it forms on the barrel will be thin and may not completely prevent oxidation from occurring. It would not be practical to employ large amounts of zinc chloride at these temperatures to correct this condition. Moreover, in many instances the ferrous body has been previously brought to a particular condition of hardness or microstructure by preheating and tempering, and if the temperature of the flux bath is too high, sufficient heat may be transferred to the ferrous body by the flux to raise its temperature above the critical point of the material such that its microstructure changes to austenite, and upon subsequent quenching, to martensite with a resultant increased hardening of the ferrous body. This may be the cause of tool breakage in subsequent machining operations. In general, for example, where barrels of 28–32 Rockwell C hardness are to be muffed, an upper temperature exceeding 1360° F. will produce a sharp increase in hardness of most alloy steels.

The optimum temperature range of the flux bath is also somewhat dependent upon the amount of zinc chloride in the composition, this ingredient, having in addition to its fluxing properties, the effect of controlling the viscosity of the flux composition. For example, we have observed that with a new bath high in cryolite (25%) and containing by weight 25% or more zinc chloride, a commercially satisfactory aluminum alloy bond may not be obtained, if the flux bath is at a temperature of 1340° F. because the resultant flux layer obtained on immersing the ferrous member in the flux bath may be too thick, but that a good alloy bond will be obtained if the flux bath temperature is in such cases made between about 1375° F. to 1400° F. or even higher, for instance, 1425° F. where the cold barrel effects a substantial temperature drop in the bath upon immersion. It has been further noted, however, that if the flux bath has been heated for a number of days at the higher temperature, some of the zinc chloride escapes as fumes and some cryolite settles out as the principal constituent of the sludge in the bottom of the furnace. If an appreciable reduction in the zinc chloride content occurs, for example, to about 20% by weight, the thickness of the flux film formed on the ferrous members will decrease, even with the bath at a temperature of 1340° F., to a point where it may be readily washed from the surface of the ferrous body by the molten aluminum and a good aluminum alloy bond be effected. Hence the temperature of the bath may be thereafter lowered to 1340° F. if desired.

The optimum temperature of the flux bath is likewise influenced to some extent by the amount of cryolite present in the composition. This essential ingredient, which promotes wetting and dissolves oxides, has the further effect when used in large amounts, of mechanically thickening the flux composition. Accordingly, a somewhat higher bath temperature is preferred when large amounts of cryolite are employed and the temperature of the bath may again be lowered when some of this fluoride salt is lost, as noted above, by sludging.

Based upon our observations, the preferred temperature range for the flux bath will be between about 1330° F. and about 1400° F. (1360° F. maximum if hardening is a factor), and the preferred composition for large scale operations will be one preferably containing the following essential ingredients:

	Parts by weight
Sodium chloride	About 25 to 35
Potassium chloride	About 25 to 35
Natural Greenland cryolite	About 9 to 20
Zinc chloride	About 15 to 25

These proportions of the essential ingredients provide a wider latitude in timing of the various operations.

The cost of the flux bath composition may be somewhat reduced by replacing a portion of the natural Greenland cryolite with a synthetic or reduction grade cryolite and replacing minor portions of one or more of the other essential salts of the composition by other salts, for example, calcium chloride. It is preferred, however, that the amount of substitute cryolite in the composition should not exceed about 50% as the present commercial grade of synthetic cryolite is an impure substance, and the presence of too great a quantity adversely affects the alloy bond between the aluminum and ferrous metal. Likewise, it is preferred in commercial operations that the calcium chloride be added after the previously named essential ingredients of the composition have been thoroughly mixed and charged into the furnace and the bath is molten. The amount added preferably will not exceed about 2½ to 5 percent by weight of the total charge in the furnace. It has further been noted that if the amount of cryolite in the composition has been reduced substantially below about 10 percent by weight, the alloy bond between the aluminum and ferrous metal will be adversely affected and the minimum percentage of this essential ingredient should be re-established.

As will be evident from the previous discussion of the flux composition, that the zinc chloride and cryolite contents do not remain constant during extended operations, and a control of the composition is therefore preferably provided to compensate for losses in the composition due to these ingredients. Various procedures were tried. By one method, additions of one or both of the critical ingredients, based upon chemical analysis, were made to the bath when tests indicated that the content of these ingredients had dropped to a point where an unsatisfactory bond between the aluminum and the steel would be obtained. This mode of bringing the bath back to its original composition was not found commercially expedient because considerable loss of zinc chloride resulted from excessive fuming when large additions of zinc chloride were made and because the added cryolite did not readily go into solution and sludged heavily.

A second method employed with better results was to ladle out approximately half of the bath content when failures of bond seemed imminent and to then restore the bath to its proper level by adding new mix to the remainder. This method was also not considered good enough for commercial operations.

A much improved method of control was then evolved by which daily additions of flux composition were made to the bath to restore its level and character. In this connection it was found that in a 600-pound furnace, about 35 pounds (about 5%) of ready mixed salt were required each day for makeup, primarily to correct for drag-out losses. Moreover, it was noted from accumulated chemical data, that the cryolite loss was approximately 2% by weight per day and that of zinc chloride approximately 1% by weight per day. The control effected was to add 35 pounds of makeup mixture per day comprising 26 pounds of ready mixed salt, 6 pounds of cryolite, and 3 pounds of zinc chloride. This daily addition effectively counteracted the cryolite and zinc chloride losses and provided a satisfactory bond each day of operation. The amount of makeup was, moreover, varied depending upon the chemical analysis of the bath, this amount sometimes exceeding the 35 pounds basic addition, in which case a portion of the bath was ladled out to provide a proper operating level after additions.

As a result of further observations, a still more flexible system of control requiring no ladling out of flux and facilitating a closer control of the composition was evolved for making up cryolite and zinc chloride losses.

It was noted, for example in connection with a new 600-pound furnace, that if it was loaded with fresh salt, satisfactory bonding operations could not be commenced during an initial 48-hour period due to seepage of salt into the porous refractory of the furnace to establish a seal and heavy sludging during this period. During this two-day period, the bath is a murky, non-translucent appearing mass. However, thereafter it changes to a clear translucent body making visible the bottom of the electrodes. When the latter stage is reached, it is an indicator that satisfactory casting operations productive of excellent bonds may be undertaken.

It was also observed that if the starting cryolite content was 25% by weight, this ingredient rapidly settled out and dropped to 20% and below after a few days, if the bath had little agitation but if mechanical agitation of the bath is provided, this settling out was at a much slower rate.

It has been pointed out above that with normal production rates, approximately 35 pounds of salt were required for makeup purposes. Employing this factor and a pre-mixed salt having substantially the following composition:

	Percent by weight
Sodium chloride	27½
Potassium chloride	27½
Natural Greenland cryolite	20
Zinc chloride	25

As the starting and/or additive mixture, the following control was evolved.

If the daily check of the flux bath showed a cryolite content between 16% and 25% by weight, no addition of salt was made. Each day the cryolite content was between 12½% and 16% by weight, a 35-pound batch of salt made up of 20% by weight cryolite and 80% by weight of the foregoing pre-mix was added. Each day the cryolite content of the bath on checking was found to be between 11% and 12½%, a 35-pound batch of salt made up of 30% cryolite and 70% of the above pre-mix salt was added. If on the daily check the cryolite content fell below 11%, a 35-pound batch of salt made up of 40% cryolite and 60% of the pre-mix salt was added.

By this method of control of the cryolite constituent of the bath it was found that additions of zinc chloride are seldom necessary other than by the pre-mixed makeup salt added to the cryolite when making additions of that ingredient. However, if the zinc chloride content dropped below 19% by weight assuming an original content of 25% by weight, additions of zinc chloride were preferably made as a mixture thereof with the foregoing pre-mix salt and cryolite, and in quantities not exceeding 20% by weight of the total salt addition. This procedure for adding zinc chloride restores the quantity in the bath to above 19%. Experience has shown that such an amount produces a flux bath having better fluidity. The described method of adding zinc chloride also eliminates excessive loss of this ingredient by smoking when the addition is made.

It will be understood that the daily addition of flux is not limited to the 35-pound amount based upon experience with a furnace capable of handling a 600-pound charge of salt but that this amount may be varied as conditions show the need for greater quantities to restore the bath level. However, it is preferred that no greater amount than 70 pounds be added in one day to a furnace of 600 pounds capacity and then only in batches where the direct cryolite addition is no greater than 30%, for experience has shown that larger direct cryolite contents may cause excessive sludging.

By using the described control it was found possible to maintain the amount of cryolite in the bath at all times between 11% and 14% and the amount of zinc chloride between 19% and 24% and obtained a 100% bond of the aluminum to the ferrous member in all operations. Obviously, the remainder of the bath comprised the other essential ingredients sodium chloride and potassium chloride and when included such additions as calcium chloride or other salts to the degree previously indicated.

The fluxing of ferrous bodies by our invention may be carried out with best results if the surface of the ferrous metal is roughened, for example, by grit blasting to obtain a larger surface area of the ferrous metal for exposure to the flux and consequently to the aluminum thereby making a stronger bond possible. Moreover, with such a greater surface area of roughened character, there is less tendency for the fluent flux to run off or to become too thin during the casting procedure, particularly in the interval between completion of the fluxing step and pouring of the molten aluminum. It will be understood, however, that good bonds may be obtained by the processes described herein without grit blasting by using either ground or turned surfaces.

It may also be noted that one of the critical aspects of the processing is the temperature of the sleeve at which the molten aluminum makes contact with the steel surface. It is difficult because of many variables present to determine this temperature and hence in the foregoing description other temperature indicators have been employed. However, it is believed that the temperature of the sleeve should be one at least above the melting point of the aluminum (1220° F.) and may serve as an additional control guide.

Prior to starting casting operations it is also preferred that the molds be preheated as by gas torch to between 500–700° F. This does not have to be repeated once casting has begun as enough heat remains in the molds after casting without again preheating. The molds are also preferably cleaned after each casting operation by blowing off with a light stream of water. The steam formed by this application of water seems to break away the salt accumulation on the side walls of the mold and provides a better operation than that obtained with a mold wash, for instance of the graphite type. In fact the use of a stop-off paint such as pyro at the tops of the barrels to prevent bonding of the aluminum is also found to be unnecessary, as any excess aluminum at the top of the casting can be machined off and no difficulty experienced even at the bond where an end feed tool is used to cut below the aluminum-steel interface. The hard brittle Fe-Al compound at the bond breaks up ahead of the edge of the cutting tool.

For a number of reasons, it is often desirable to start cooling of the muffed cylinders after pouring of the aluminum has begun. This is accomplished by an air-water vapor spray directed against the interior of such cylinders. This cooling promotes directional solidification of the aluminum and thereby avoids shrinkage cavities. Moreover, such cooling prevents distortion of the ferrous metal and aids in maintaining a proper hardness level where such is necessary. In the latter connection, if the part is not cooled, heat imparted by the molten metal may maintain its temperature within the tempering range for a sufficient time to decrease the hardness of the previously hardened ferrous member to a degree below its desired hardness specification.

Where it is desired to provide a longer cooling period for the molten aluminum after pouring in which it remains in a molten condition so that the flux may be more readily completely displaced before the aluminum solidifies, a lower melting point aluminum composition may be used. Such a composition may be obtained by the addition of silicon, tin or other elements. For example, when used in amounts approximately 11% by weight of the composition, silicon will provide a melting point as low as 1070° F. Lesser amounts will, of course, determine the temperature for a melting point between

1070° F. and 1220° F. The use of silicon in the aluminum melt has a further advantage of providing a thinner and stronger alloy bond between the cast layer and the ferrous metal surface.

For the purpose of giving those skilled in the art some better understanding of the possibilities of our invention, the following illustrative examples are given:

Example I

A steel sleeve of 2½" diameter and ¼" wall thickness having a cleaned exterior surface roughened by grit blasting, was immersed in a flux bath of molten salts maintained at a temperature of about 1400° F. in a "Lindberg" electric resistance furnace and kept in the bath until it reached the temperature thereof.

The composition of the bath was substantially as follows:

	Parts by weight
Sodium chloride (NaCl)	24.5
Potassium chloride (KCl)	24.5
Zinc chloride ($ZnCl_2$)	24.5
Natural Greenland cryolite (Na_3AlF_6)	24.5
Calcium chloride ($CaCl_2$)	2.5

When the sleeve reached the temperature of the bath, it was immediately removed and placed in a steel mold of a size to form upon casting an aluminum muff ¾" thick and 4" long at one end of the sleeve. Within 31 seconds of removal of the sleeve from the bath, molten aluminum of about 1220° F. melting point and at a temperature of 1400° F. was poured into the mold around the sleeve. About 24 seconds was utilized for pouring. The cast member was then permitted to air cool. Visual and microscopic examination of the alloy bond between the aluminum and steel disclosed that an excellent alloy bond was obtained. It was also evident there had been excellent wetting of the steel, and that the alloy bond was continuous, complete and free of any flux or oxide inclusions.

Example II

A steel sleeve of the character described in Example I was provided with a cast aluminum muff as there described, the molten flux bath in this example being maintained at a temperature of about 1350° F. The composition of the bath was substantially as follows:

	Parts by weight
Sodium chloride	40
Potassium chloride	40
Natural Greenland cryolite	20

The aluminum had a melting point of 1220° F. and was used at a temperature of 1400° F. The elapsed time between removing the sleeve from the bath and the start of pouring was 9.5 seconds, and the pouring time was 8 seconds. Visual and microscopic examination of the cast member disclosed a very good bond between the aluminum and steel having an alloy layer between .0005" and .001" thickness. Good wetting of the steel occurred during pouring, and the bond was continuous, complete and free of any flux or oxide inclusions.

Example III

An aluminum muff was cast about a steel sleeve of the character described in Example No. 1 and in the manner there stated, the flux being maintained at 1400° F., and the molten aluminum having a melting point of about 1220° F. and a working temperature of about 1400° F. The composition of the flux bath was substantially as follows:

	Parts by weight
Sodium chloride	7
Potassium chloride	44
Zinc chloride	34
Natural Greenland cryolite	15

The time interval between removal of the sleeve from the flux bath and the start of pouring was 30 seconds, and the pouring time was 10 seconds. Visual and microscopic examination disclosed a good bond and good wetting.

Example IV

A steel sleeve of the size described in Example I was fluxed and provided with a cast aluminum muff in the manner there stated, using a flux bath maintained at a temperature of 1400° F. and molten aluminum having a melting point of 1220° F. and a working temperature of about 1400° F. The composition of the flux bath was substantially as follows:

	Parts by weight
Sodium chloride	25
Potassium chloride	25
Zinc chloride	25
Natural Greenland cryolite	25

The time interval between removing the sleeve from the flux bath and start of pouring was 30 seconds. The pouring time was 13 seconds. Visual and microscopic examination disclosed good wetting and an excellent alloy bond.

Example V

A steel sleeve of the character described in Example I was provided with a coating of flux and a cast aluminum muff in the manner there stated, the flux bath being maintained at a temperature of 1300° F. and the molten aluminum having a melting point of about 1220° F. and a working temperature of about 1400° F. The composition of the flux bath was substantially as follows:

	Parts by weight
Sodium chloride	35
Potassium chloride	35
Zinc chloride	15
Natural Greenland cryolite	15

The elapsed time between removal of the sleeve from the bath and the start of pouring was 11 seconds, and the pouring time was 8.5 seconds. Visual and microscopic examination disclosed a good alloy bond of about .001" thickness.

Example VI

A steel sleeve of the character described in Example I was fluxed and provided with a cast aluminum muff as there described utilizing a flux bath at a temperature of about 1400° F. and molten aluminum having a melting point of about 1220° F. at a working temperature of about 1400° F. The flux composition was substantially as follows:

	Parts by weight
Sodium chloride	35
Potassium chloride	35
Zinc chloride	15
Natural Greenland cryolite	15

The elapsed time between removal of the sleeve from the flux and the start of pouring was 30 seconds, and the pouring time was 10.5 seconds. Visual and microscopic examination disclosed a good alloy bond having about .001" thickness.

Example VII

A 10½" long shouldered barrel of 5¾" diameter with a wall thickness of about 5/16" and a ⅜" flange, made from a 8740 SAE steel, was grit blasted and immersed and heated in a molten flux bath maintained at a temperature of 1400° F. in a Lindberg electric resistance furnace until the barrel reached the temperature of the bath. It was immediately removed and placed in a steel mold arranged to form a cast aluminum muff of about ¾" wall thickness and 4" long adjacent one end of the

sleeve. The flux bath had substantially the following composition:

	Parts by weight
Sodium chloride	25
Potassium chloride	25
Zinc chloride	25
Natural Greenland cryolite	25

Within 35 seconds of removal of the barrel from the bath and its positioning in the mold, molten aluminum having a melting point of 1220° F. and a working temperature of 1430° F. was poured into the mold around the steel barrel. Two minutes and fifty seconds was utilized for pouring time including time to head the aluminum with additional molten metal to compensate for shrinkage. The cast member was then permitted to cool. Visual and microscopic examination disclosed an excellent alloy bond.

Example VIII

A steel barrel of the character of the preceding example was immersed and heated in a molten flux bath maintained at 1350° F. in an Ajax submerged electrode salt bath furnace having a capacity of 600 lbs. of salt. The flux had substantially the following composition:

	Parts by weight
Potassium chloride	35
Sodium chloride	35
Zinc chloride	19
Natural Greenland cryolite	11

As soon as the sleeve reached the temperature of the bath, which required about 3½ minutes immersion therein, it was immediately removed and placed in a steel mold fixture into which molten aluminum having a melting point of about 1220° F. and a working temperature of about 1350° F. was poured within 20 seconds of the time the sleeve was removed from the bath, the pouring time being about 8 seconds. An excellent alloy bond was obtained.

Example IX

A shouldered steel barrel of about 5¾" diameter with a wall thickness of about 3/16 inch, a ⅜ inch flange and a length of about 10½ inches was sand blasted in a "Wheelabrator" cabinet on its exterior surface area to which an aluminum muff is to be cast. It was then placed in a "Detrex" degreaser to remove any grease, and following this painted with a "Pyro" paint to protect the areas to which the aluminum was not to bond.

The barrel was then immersed in a flux bath of molten salt flux heated to a temperature of 1400 to 1425° F. in an immersed electrode "Ajax" electric salt bath furnace of 185 lbs. capacity and kept immersed for 3½ minutes. The temperature of the barrel at the elapsed time, as determined by a thermocouple attached to the side wall of the barrel during immersion, was between 1340 to 1360° F. There was a drop of 50 to 75° F. in the bath temperature experienced on immersion.

The flux bath was prepared by thoroughly mixing together substantially:

	Parts by weight
Sodium chloride	25
Potassium chloride	25
Zinc chloride	25
Natural Greenland cryolite	25

and charging the same into the furnace. After the bath was molten, approximately 2½% of calcium chloride based on the weight of the total charge was added.

The flux treated barrel after heating to the above-stated temperature was then removed from the hot salt flux and placed in a metallic mold fixture preheated to 500–700° F. and constructed to enable an aluminum muff about 6" long and 1¼" thick and weighing about 19 lbs. to be cast around the barrel. Molten aluminum at a temperature between 1325° and 1350° F. prepared from 99% pure ingot having a melting point of about 1220° F. was immediately poured in the mold by hand ladles to a height of 6½". Pouring of the aluminum was started within 25 seconds from the time the barrel was removed from the hot salt flux and pouring continued as rapidly as possible until the mold was topped. About 10 seconds was required for filling the mold. An operator stood by with a ladle of aluminum to fill in any shrinkage cavities developed during solidification of the aluminum.

During pouring commencing when the mold was half filled, the barrel was air-water cooled by an air-water vapor spray directed against the inside thereof. After the aluminum solidified, the barrel was removed from the fixture and quenched in oil. Examination of the bond disclosed it to be excellent.

Example X

A shouldered steel barrel of about 5¾" inside diameter and between 3/16" to ⅜" wall thickness and a length of about 10½", was rough machined from forgings of an SAE 8640 or AISI TS–8640 or SAE 4140 steel and heat treated, austenitized, quenched in oil, and tempered to a hardness of 28 to 32 Rockwell C. The barrel was then cleaned in a "Mahon" washer to remove any grease or dirt, then shot blasted in a blast cabinet to blast clean the outside of the barrel and remove any shine from the surfaces to be aluminum muffed.

The barrel was immersed in a flux bath of molten salt flux heated to a temperature between 1330° F. and 1350° F. preferably 1340° F. in an immersed electrode Ajax electric salt bath furnace of 600 lbs. capacity and kept immersed for 3½ minutes. The flux bath was prepared from a homogeneous mixture of substantially the following ingredients in substantially the amounts stated, these ingredients being in granular form of 50 to 200 mesh and of 99% plus purity:

	Parts by weight
Potassium chloride	27½
Sodium chloride	27½
Zinc chloride	25
Natural Greenland cryolite	20

After the bath was molten, approximately 2½% by weight of calcium chloride, based upon the weight of the total charge, was added.

The flux-treated barrel was then removed from the hot salt flux and promptly placed in a preheated Huckins mold fixture previously heated to a temperature between 500 to 700° F. and constructed to enable an aluminum muff about 6" long and 1¼" thick, and weighing about 19 lbs. to be cast around the barrel. Molten aluminum at a temperature between 1315° F. and 1335° F. prepared from 99% pure ingot having a melting point of about 1220° F. was immediately poured into the mold with hand ladles to above the muff area and topped to prevent shrinkage cavities in the muff. Air-water cooling of the inside of the barrel was commenced during pouring, by an air-water spray applied to the inside of the barrel when the mold was filled to a height of 2" to 3" of aluminum. Pouring of the aluminum was commenced promptly, i.e., between 10 to 20 seconds after the barrel was removed from the salt flux bath (the average for a run was 15 seconds) and pouring made continuous during the entire pouring cycle. The time to fill the mold with molten aluminum was between 6 to 10 seconds (the average for a run was 8 seconds), this time interval not including the time required for topping off the mold. The air-water spray cooling was provided by a movable spray head operating with an air line pressure of 30 to 40 pounds per square inch, and arranged to move upwardly in the barrel at a rate to require between 2¼ to 2½ minutes to move over the cast area. The rate of water flow in the head was adjusted such that no actual streams of water were ejected from the spray head, but rather the water was in the form of vapor. Moreover, the head was adjusted so that the vapor was not excessive

to the extent of spraying over into the molten aluminum on pouring.

After the aluminum had solidified, the barrel was removed from the mold and quenched in tap water.

Examination of the cast muff showed an excellent continuous bond formed with the steel barrel.

From the above description of our invention and examples, it will be evident that various modifications and substitutions will be obvious and others will readily suggest themselves to those skilled in the art, all however without departing from the spirit and scope of our invention.

We claim:

1. In a process of producing a duplex metal structure comprising a hollow ferrous metal body and a cylindrical cast aluminum muff having an alloy bond therewith comprising positioning said body in a mold providing a cavity adjacent said body shaped to form said muff, pouring molten aluminum into said cavity to form said muff, and directing an air-water vapor spray against the interior of said body after starting pouring of the aluminum but before it has been completed.

2. In a process of producing duplex metal structures comprising a cylindrical ferrous metal body and a surrounding cast aluminum muff having an alloy bond therewith comprising positioning said body in a mold providing a cavity adjacent the outer cylindrical surface of said body shaped to form said muff and providing access to the interior cylindrical surface of said body, pouring molten aluminum into said cavity, to form said muff, after commencing pouring directing a ring of air-water vapor against the interior cylindrical surface of said body opposite the poured aluminum and moving said ring of vapor through the area of contact of said molten aluminum and in step with said pouring.

3. The process of producing a duplex metal structure comprising a cylindrical heat hardened ferrous metal body and a supporting cast aluminum body having an alloy bond therewith, comprising immersing said ferrous body in a bath of fluent molten flux having a temperature between 1250° F. and 1450° F. and consisting essentially of cryolite and chlorides, maintaining said body in said bath for a time interval sufficient to provide said body when withdrawn therefrom with a continuous layer of said fluent flux on the portion of said ferrous body where it is to be bonded with said aluminum, withdrawing said ferrous body from the flux bath, positioning the flux layered ferrous body in a mold providing a cavity adjacent said ferrous body shaped to form said aluminum body, pouring molten aluminum at a temperature between 1325° F. and 1425° F. into said cavity while said flux of said flux layer is still fluent, to form said aluminum body, said molten aluminum displacing said fluent flux ahead of it in the cavity and forming when set a ferro aluminum alloy bond with said ferrous body, directing a ring of air water vapor against the surface of said ferrous body opposite the poured aluminum during pouring thereof and moving said ring of vapor through the area of contact of said molten aluminum and substantially in step with said pouring.

4. The process of producing a duplex metal structure comprising a cylindrical heat hardened ferrous metal body and a supporting cast aluminum body surrounding said ferrous metal body and having an alloy bond therewith, comprising immersing said ferrous body in a bath of fluent molten flux having a temperature between 1250° F. and 1450° F. and consisting essentially of cryolite and chlorides, maintaining said body in said bath for a time interval sufficient to provide said body when withdrawn therefrom with a continuous layer of said fluent flux on the portion of said ferrous body where it is to be bonded with said aluminum, withdrawing the said ferrous body from the flux bath, positioning the flux layered ferrous body in a mold providing a cavity adjacent the outer cylindrical surface of said ferrous body shaped to form said aluminum body, providing access to the interior cylindrical surface of said ferrous body, pouring molten aluminum at a temperature between 1325° F. and 1425° F. into said cavity while said flux of said flux layer is still fluent to form said aluminum body, said molten aluminum displacing said fluent flux ahead of it in the cavity and forming when set a ferro aluminum alloy bond with said ferrous body, following start of pouring of said aluminum directing a ring of air water vapor against the interior cylindrical surface of said ferrous body opposite the poured aluminum and moving said ring of vapor through the area of contact of said molten aluminum and substantially in step with said pouring.

5. The process of producing a duplex metal structure comprising a heat hardened ferrous metal body and a cast aluminum body having an alloy bond therewith, comprising immersing said ferrous body in a bath of fluent molten flux having a temperature between 1250° F. and 1450° F. and consisting essentially of cryolite and chlorides, maintaining said ferrous body in said bath for a time interval sufficient to provide said ferrous body when withdrawn therefrom with a continuous layer of said fluent flux on the portion of said ferrous body where it is to become bonded with said aluminum, withdrawing said ferrous body from the flux bath and immediately positioning the flux layered ferrous body in a mold providing a cavity adjacent said ferrous body shaped to form said aluminum body and then substantially immediately pouring molten aluminum at a temperature between 1325° F. and 1425° F. into said cavity while said flux of said flux layer is still fluent to form said aluminum body, said molten aluminum displacing said fluent flux ahead of it in the cavity and forming when set a ferro aluminum alloy bond with said ferrous body, and during said pouring of aluminum directing a spray of air water vapor against the surface of said ferrous body opposite that contacting said aluminum.

6. The process of producing a duplex metal structure comprising a ferrous metal body and a facing of cast aluminum alloy having an alloy bond therewith, comprising immersing said body in a bath of fluent molten flux consisting essentially of fluorides and chlorides and having a temperature above the melting points of the flux and aluminum alloy and not exceeding substantially 1450° F., maintaining said body in said bath for a time interval sufficient to provide said body when withdrawn therefrom with a continuous layer of said flux on the portion of the body where it is to be aluminum faced, said body when withdrawn therefrom being in a heated condition and said flux thereon being fluent, withdrawing said body from the said flux bath and positioning the flux layered body in a mold providing a cavity adjacent said body shaped to form said facing, while said flux of said flux layer is still fluent casting between said body and said mold a facing of molten aluminum alloy at a temperature above its melting point and not substantially exceeding 1425° F., said molten aluminum displacing said fluid flux ahead of it in the cavity and forming when set a ferro-aluminum alloy bond with said body, and directing an air water vapor spray against the surface of said ferrous metal body opposite that to which the aluminum is cast during filling of said cavity with molten aluminum but after filling has started.

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