

DYNAMIC VACUUM TREATMENT OF MOLTEN ALUMINIUM AND ITS ALLOYS

Aksel Aarflot
R & D Manager for Casting Sector

Frank Patak
Chartered Engineer, Metallurgical R & D

A/S Årdal og Sunndal Verk
Sunndal Verk
6601 Sunndalsøra
Norway

Abstract

The dynamic vacuum treatment is a method of treating the melt in which metal transfer, alloying and vacuum treatment are combined in one operation. The whole process is performed by means of vacuum and under vacuum. This method, which has been developed and patented by A/S Årdal og Sunndal Verk (ÅSV), offers a good alternative to the chlorine treatment of aluminium melts. The method permits high productivity and has no environmental problems. It was developed for and is being used in casting shop furnaces designed for static vacuum treatment. ÅSV now have six years' production experience of this new method, which has been used for the production of all current alloys and metal qualities from potroom metal. The method will be described, an account will be given of experience gained and the latest development results will be submitted.

Introduction

We installed our first vacuum furnace in 1965 and added several new ones in 1967, and for the next two years, our treatment of the melt was by the static vacuum method. In 1969, development work started on the dynamic vacuum treatment process, and in time became the only method used for treating metal to be cast by the D.C. process. The principle is very simple in that one and the same operation is used for transferring molten metal from a mixer furnace to a casting furnace and for performing the necessary treatment of the melt and stirring in of alloying metals at the same time.

This process which has been developed and patented by A/S Årdal og Sunndal Verk (ÅSV) and sold to a number of aluminium smelters was presented at the 100th AIME Annual Meeting in 1971 (1) for the first time. Since then, the process has been under continual development, and new results and knowledge will be submitted in this paper.

Principles and theory of the process

The dynamic vacuum treatment consists in the molten metal being sucked into a vacuum furnace through a nozzle. This results in an expanding metal jet which strikes the bath of molten metal at high speed as it builds up. This produces a vigorous stirring in of the alloying elements which are added to the empty vacuum furnace before it is evacuated.

The general purpose of treating an aluminium melt is to reduce the content of hydrogen (H₂), sodium (Na) and non-metallic particles.

How does the dynamic vacuum treatment achieve this, and what process parameters must we pay attention to?

Reducing the hydrogen content

First we must examine what degree of vacuum is necessary for providing satisfactory degassing.

According to Ransley this can be calculated by the following equilibrium formula:

$$\lg S = \frac{2,760}{T} + \frac{1}{2} \lg P_{H_2} + 1,356$$

in which S is the solubility at equilibrium, and P_{H₂} is the partial pressure of the hydrogen in the furnace atmosphere.

This gives, at equilibrium, $P_{H_2} = 4.8$ torr (mm Hg) at 750°C with a hydrogen content of 0.1 ml/100 gr. This means that P_{H_2} can be up to 40% of the total pressure when this is 10 torr, without the hydrogen content exceeding 0.1 mg/100 gr. On this basis, 10 torr should be sufficient to reduce the hydrogen content to 0.1 ml/100 gr. even without equilibrium, provided conditions are otherwise suitable.

We know that active hydrogen is found dissolved in the molten aluminium and that the actual degassing is determined by the velocity of diffusion for hydrogen in the melt. In a steel melt, degassing occurs under vacuum very simply because the velocity of diffusion and the hydrogen content is substantially larger. To obtain an efficient degassing in an aluminium melt, it is therefore necessary to pay special attention to the design of the process. To cause the largest possible expansion in the jet and thus the largest possible surface against the vacuum and the shortest possible diffusion distance, the nozzle must be so shaped as to produce a turbulent flow of metal, or gas should be introduced into the nozzle. Further the life of the metal in its atomized state should be as long as possible, which means that the jet must be as long as practicable.

In addition to the degassing which takes place in the jet itself, there is also a vigorous stirring in the melt as it builds up, and which thus, in addition, benefits by a static vacuum treatment.

Reducing the sodium content

Neither in theory nor in practice is there any difficulty in greatly reducing the content of sodium by vacuum treatment, but the presence of sodium fluoride and magnesium, and particularly these two together, will reduce the effect. This means that the reduction of the sodium content will be dependent upon how well the furnace is kept clean, and this in turn is often a function of the shape of the hearth. This has been confirmed by A. Yazawa (2) through laboratory experiments in removing sodium from potroom metal. Apart from this, the same theory will apply to the reduction of the sodium content as for hydrogen (H_2) as sodium is a volatile metal which is liberated in gas form. All steps taken to reduce degassing will also help to reduce the content of sodium.

It can also be mentioned here that since hydrogen and sodium are liberated from the metal jet and from the melt, they will provide a protective atmosphere against the oxidation of the metal from oxygen remnants in the furnace atmosphere. (The combustion of hydrogen and sodium can, in fact, be seen in the hearth at the start of metal transfer). When treating the melt in normal atmosphere, the removal of hydrogen and sodium is obstructed by a

thick, continuous, skim of oxide, and a layer of dross. In dynamic vacuum treatment, this oxide skim is very thin, and discontinuous, permitting the hydrogen and sodium to escape easily from the melt.

Reducing the content of non-metallic particles

Several trials and follow-ups in production have shown a clear reduction in the content of non-metallic particles and oxygen in the melt. We have no theory to explain this, but suggest, as a hypothesis, that the smallest particles which are dispersed inasmuch as the metal jet expands, are captured by the thin layer of dross on the surface of the melt through which the jet is "filtered". The larger particles will, perhaps, on account of the vigorous stirring of the melt, be carried to the dross on the surface and be captured there. The stirring may also cause small particles to form clusters.

Alloying

In order to effect alloying quickly and efficiently, steps must be taken to prevent the alloying element from oxidising. It must melt quickly, and the metal as it melts must be carried out into the bath as quickly as possible, so as to maintain the highest possible concentration gradient between the piece of alloying metal and the surrounding bath. This is particularly important in the case of alloying elements which have a high melting point and which form intermetallic phases with aluminium at comparatively low concentrations.

In the conventional method, it is usual to add alloying metals in the form of master alloys, in order to reduce the danger of oxidation, to be able to operate with a lower melting point, and to reduce the need for stirring.

The addition of alloying metals using the dynamic vacuum treatment is performed with the elements in the pure state, these being added to the empty vacuum furnace before evacuation. The elements in question here are magnesium, zinc, silicon, copper, zirconium and possibly others. That this method can be adopted, and with advantage, is due to the minimal danger of oxidation, and particularly to the constant vigorous stirring of the melt which maintains throughout a high concentration gradient in the melt between the alloying elements (all required elements together) and the surrounding bath.

Description of equipment and process

Our vacuum furnaces were built for static vacuum treatment, and our method of dynamic vacuum treatment which we use in production has been adapted to suit these furnaces, along with the limitations this imposes. Our furnace lay-out consists of a tandem system with mixer and vacuum/casting furnace. Both furnaces are oil-fired and tilting. The furnaces are interconnected by a special transfer launder which terminates in a nozzle in the vacuum furnace (fig. 1). The mixer furnace is charged with about 10% cold metal (return metal) and is filled up with potroom metal. The dross is skimmed off the melt, and the temperature adjusted to the correct value for transfer to the vacuum furnace, which has been evacuated in advance.

The last operation before the vacuum furnace is closed for evacuation is to add the necessary quantities of alloying elements based on the weight of the charge (batch). When the pressure in the vacuum furnace has been brought down to 10 torr - after 5 - 10 minutes - the transfer launder is filled with metal, the sealing plate in front of the nozzle orifice is withdrawn (fig. 1), and the dynamic vacuum treatment is in progress. The metal flows through a specially designed graphite nozzle with a velocity of about 7 metres per second, and with a capacity of some 1,000 kg/min.

The vacuum furnace is supported on load cells, so that the amount of metal transferred can continually be monitored, digitally, and the transfer operation can therefore be terminated when the desired charge weight has been reached. If it is desired to operate with constant charge weight, contact electrodes are used which give a light signal when the metal in the vacuum furnace has reached the pre-determined level.

The dynamic vacuum treatment is terminated by closing the main valve to the vacuum pumps, and air is let into the vacuum furnace by a special pressure equalizing valve. Air must not be drawn in through the nozzle together with the molten metal. When terminating transfer, this is prevented by closing the nozzle with the above-mentioned sealing plate before the launder is completely empty, and whilst air is released into the vacuum furnace. After this, we merely let the metal remaining in the launder run down into the furnace through the nozzle.

On completion of transfer, the alloying operating and the melt treatment are also complete. Apart from the most highly alloyed alloys, there is no need to stir the melt. After skimming off the dross in the vacuum furnace, and half-an-hour's holding time with, if necessary, temperature adjustment, the metal is ready for pouring.

Grain refiners are added as rod during pouring, but they can also with good results, be added together with the alloying elements in the empty vacuum furnace.

With our existing production equipment, we must, when batching AlMg5 alloy, flux with gas in the mixer furnace, in order to reduce the initial sodium level. This is straight-forward, since this is unalloyed aluminium. The sodium content can also be reduced to less than 3 ppm, after alloying, by fluxing in the vacuum furnace with nitrogen under vacuum.

Application of the process

Products

Of our output of some 120,000 mto per year, 100,000 - 105,000 mto per year are poured in a D.C. casting machine. Of this, some 70 is alloyed metal. The alloys range from AlMn1 to AlZnMgCu (AA7001) with the main weight on AlMgSi 0.5 (AA6063), AlZnMgZr, AlMg1 and AlMn1. Some of the AlZn4Mg is supplied in bright quality. A comparatively large proportion (two thirds) of the unalloyed metal is supplied as lithographic and foil quality for which particularly clean metal is required. All the metal to be cast by the D.C. machine is subjected to dynamic vacuum treatment as the only treatment. Even though we have not produced all variants of alloys and qualities, the range is nevertheless sufficient to demonstrate that the method is of general applicability for all casting centres in aluminium smelters.

Capacity

To manage this production we have three D.C. casting units linked to two tandem groups each, i.e. in all six tandem groups, each consisting of one mixer furnace and one vacuum furnace, each with a capacity of 20 mto. As already mentioned, these installations were built for static vacuum treatment, and represent today an over-capacity. Today, we use two and a half casting centres for 105,000 mto, but with full utilization, we could easily manage with two D.C. centres.

With the set-up we have today, we expect to be able to average ten and a half charges per day for AlMgSi 0.5 (AA6063), operating continuously. With an average net charge size of 16 mto, this gives a capacity per 24 hours of 168 mto and an annual capacity of 55,000 mto. One furnace charge is then always poured as one casting batch.

Results/quality

Figs. 3, 4 and 5 summarize the quality criteria of interest stating values before and after dynamic vacuum treatment for unalloyed aluminium and some alloy groups. Each graph represents the results from at least 20 individual charges. These charges were produced according to standard routine, either in normal production, or at the experimental centre which is identical with the production units. The graphs indicate the frequency distribution of hydrogen, sodium and, to some extent, non-metallic inclusions in the aluminium melt, before (a) and after (b) dynamic vacuum treatment.

In addition to a substantial reduction in the content, it is worth noting the reduction in the standard deviation after the treatment from charge to charge. In other words, we get a better and absolutely more uniform quality after dynamic vacuum treatment.

The hydrogen content is determined by neutron activation analysis, and the content of non-metallic particles by a metallographic method (1).

In earlier trials, we found that the oxygen content, determined by heat extraction, is reduced by 45% in AA6063 to 6 ppm \pm 1.5.

Future prospects

As already mentioned, the vacuum furnaces which we are using for dynamic vacuum treatment process were built for static vacuum treatment. This imposes substantial limitations on the results which can be achieved by this new process. In new models, attention will be paid to this in the design of the hearth, in order to allow optimal jet length, metal dispersion and stirring effect. The furnaces will be built to facilitate cleaning. With the new design, we will be able to give effective dynamic vacuum treatment to charges of 50 mto.

It will be possible to follow up with static vacuum treatment after the dynamic part, at the same time fluxing the melt with gas to produce a vigorous stirring effect. This will provide a more efficient removal of hydrogen, sodium and non-metallic particles. The particles will be removed by their forming clusters, and the clusters will be captured by the dross.

Further it will be possible to cut out the mixer furnace, charging the vacuum furnace direct from several tapping crucibles lined up in series.

All these new measures, which will be introduced in the near future, will mean a further improvement in the quality of the products treated by the dynamic vacuum process, and also a further increase in capacity and productivity, and thus better economy.

Summary and conclusions

Even though we have not had the opportunity of making direct comparison between dynamic vacuum treatment and chlorine fluxing, we feel certain that this new process is an attractive alternative to chlorine fluxing with respect to capacity, quality, economy and, not least, the environment. With the new equipment which will be ready for operations in the near future, the dynamic vacuum treatment process will be a clear and necessary alternative to chlorine fluxing, and the process will have great prospects in the future.

References

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Figure 1

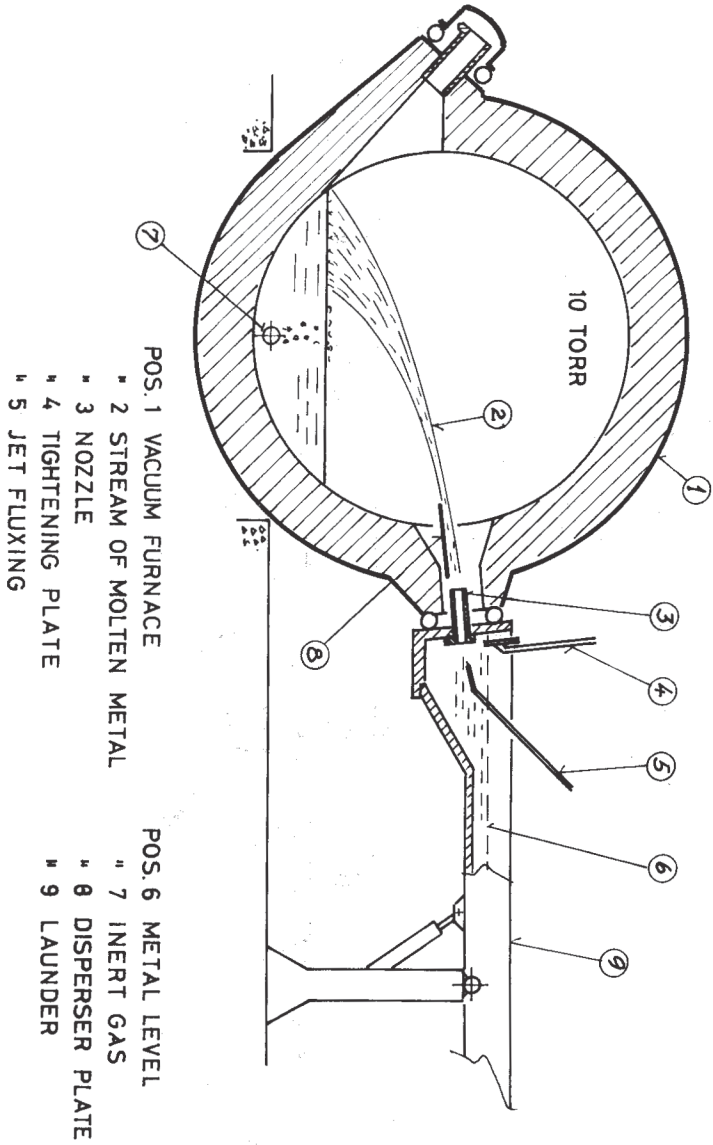
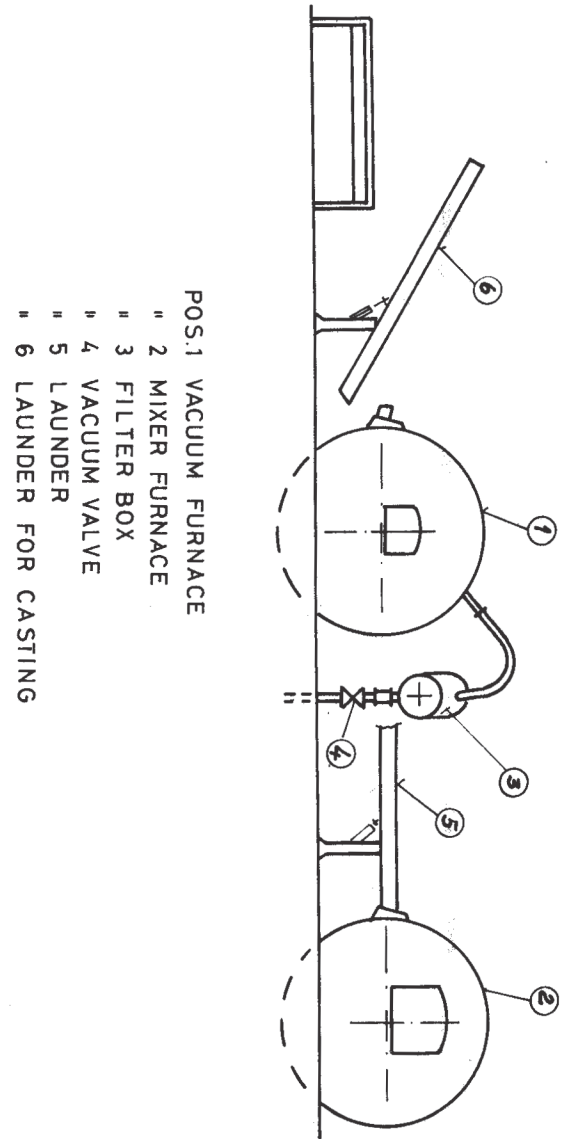


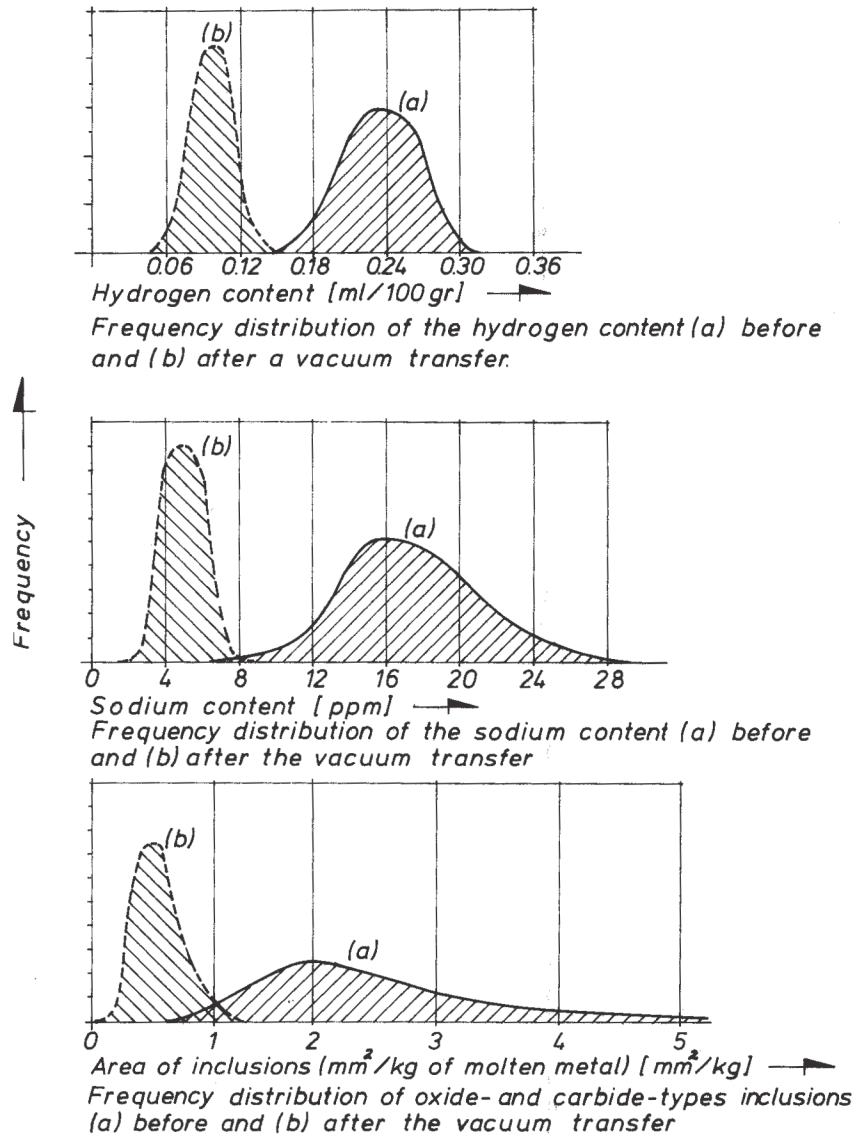
Figure 2



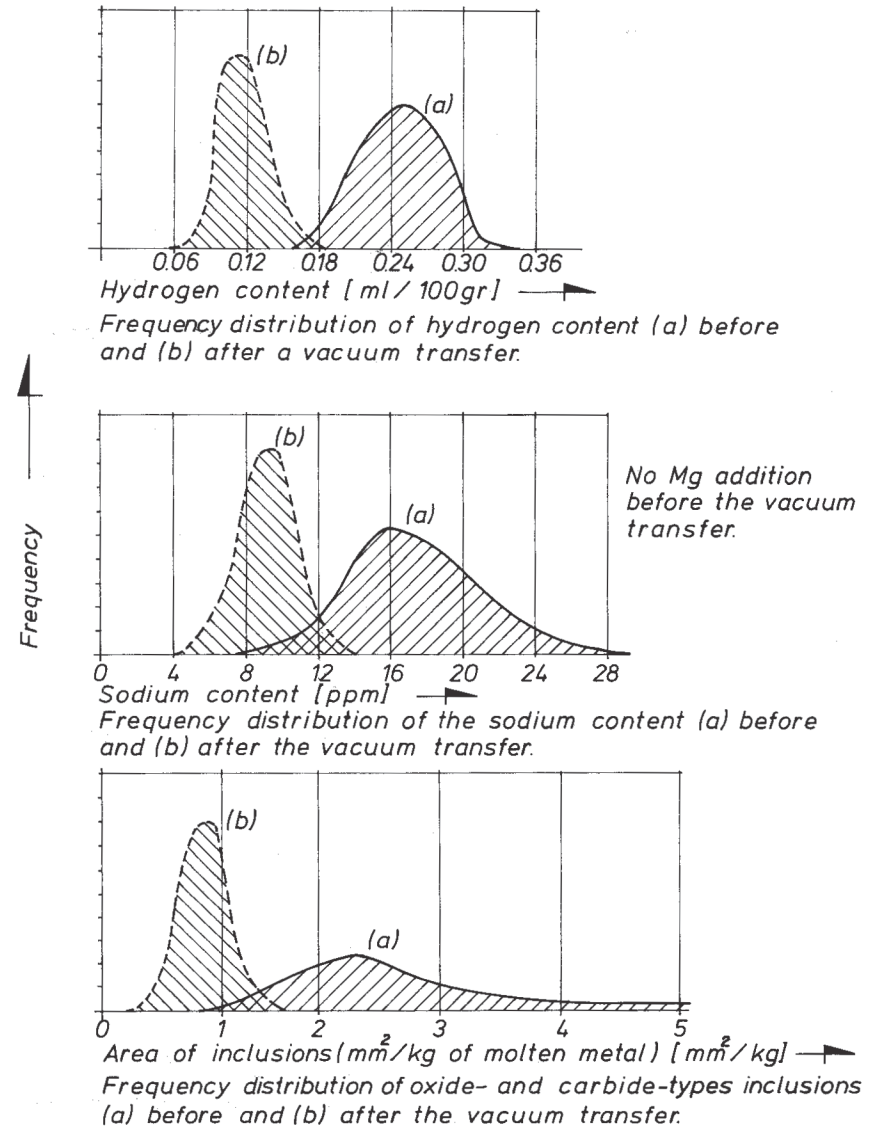
Vacuum Transfer

Figure 3

Alloy: 99,5% Al Pressure: >1-10 torr
 Transferred metal quantity: 0,9 mto/min.



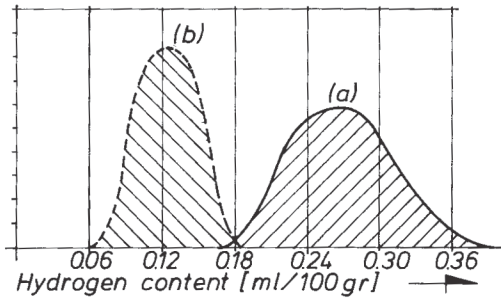
Alloy: AlMgSi 0,5 Pressure: >1-10 torr
 AlMgSi
 AlMg 1 Transferred metal quantity: 0,9 mto/min.



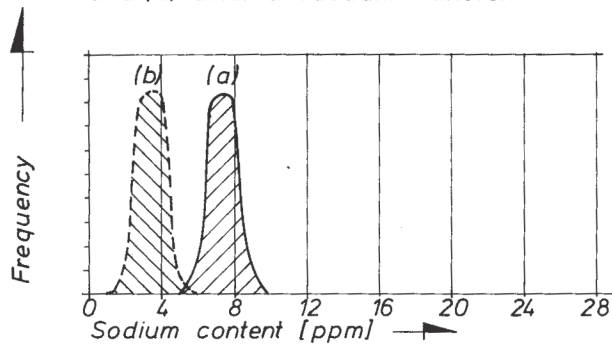
Vacuum Transfer

Figure 5

Alloy: Al Mg 2 Pressure: >1-10 torr
 Al Mg 3
 Al Mg 5 Transferred metal quantity: 0.9mto/min.



Frequency distribution of the hydrogen content (a) before and (b) after a vacuum transfer.



No Mg addition before the vacuum transfer.

Frequency distribution of the sodium content (a) before and (b) after the vacuum transfer. Gasfluxing before the vacuum transfer.