The Effect of Laminar Barrier Inerting on Cast Part Yields

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ABSTRACT

Laminar Barrier Inerting is a proven method for lowering the amount of dissolved gases and of slag formation in induction furnace melts. These benefits improve the quality of parts and part yields. Gas holes and slag cause a significant portion of rejections in precision cast parts. These defects are reduced when using Laminar Barrier Inerting. Part yield data and mechanisms of improvement are discussed.

INTRODUCTION

Increasing part yields and part quality are critical in the drive to lower investment casting costs. While many factors affect yield, induction furnace inerting can be an important tool in raising yields and quality.

Laminar Barrier Inerting (LBI) is a patented technique' developed by Union Carbide Industrial Gases Inc. to inert open ended enclosures. It uses porous elements to provide a low velocity layer of inert gas, creating a gas curtain over the open end' of an enclosure. There is very little mixing between the atmosphere and the barrier. No purge gas is required. Oxygen contents of less than 1% and nitrogen contents less than 4% in the headspace of an induction furnace crucible are typica 12 A typical installation is shown in Figure 1.

It is difficult to separate all the factors that affect yield. However, comparisons can be made between non-inerted and inerted heats if most factors are held constant. The best way to do this is to compare otherwise identical parts that have been produced from heats with and without inerting. Data on reject rates due to gas holes and slag are presented.

Four precision investment foundries provided information for this paper; Union Carbide Industrial Gases expresses its appreciation to those foundries.

GAS DISSOLUTION IN METALS

The equilibrium amount of dissolved gas is related to the partial pressure of the gas in the surrounding atmosphere by the equation for oxygen:

$$\%\underline{O} = C\sqrt{po_2}$$

Similar equations exist for nitrogen and hydrogen. *C* is determined from the thermodynamics of dissolution for the particular gas.

For air-melted heats, the oxygen content in air is 21%, so p_{O_2} is 0.21; for LBI-protected heats, the oxygen content is less than 1% and the p_{O_2} is 0.01 or less. If equilibrium were attained then $\%\underline{O}$ would drop to:

$$\sqrt{\frac{0.01}{0.21}} = .22$$

of the air-melted value. There are kinetic factors that prevent the melt from reaching equilibrium, but

the driving force is still p_{O_2}, so the reduction in dissolved gas should still occur.
The nitrogen content of air is 79%, so $p_{N_2} = .79$, and the nitrogen content for the LBI-protected heats is 4%, so $p_{N_2} = 0.04$. The equilibrium nitrogen LBI-protected value should be:

$$\sqrt{\frac{0.04}{0.79}} = .22$$

of the air-melted value.

This reduction in driving force should result in reduced gas porosity. During solidification, the solubility of the gases in metal decreases, and gas bubbles form. These bubbles usually do not have enough time to float out of the mold, and porosity forms. If ther is less dissolved gas in the metal before solidification, there should be less porosity in the final product.

Even at moderately low levels of dissolved gases, gas holes can occur due to interdendritic enrichment[3]. As the part solidifies, the concentration of solutes, such as dissolved gases, increases in the remaining liquid. When this concentration reaches the critical value for buble formation, porosity occurs.

Dissolved oxygen can also cause, in high carbon alloys, pinholes from carbon monoxide. While this is not operative in these cases, it can be of concern for certain castings.

DEOXIDATION AND SLAG INCLUSIONS

Normally, the way to prevent gas holes from dissolved oxygen is by proper deoxidation. However, deoxidation forms oxide products. If these are not trapped in the bulk slag, they can end up in the product. Reducing dissolved oxygen levels by inerting can reduce the amount of deoxidation required, lessening the chance that deoxidation products can cause harm.

Slag inclusions can also occur from entrained slag or reoxidation. Protecting the bath from the atmosphere after the surface slag is removed can reduce the amount of reoxidation. Less slag formed during the melt can reduce the amount of entrained slag. Laminar Barrier Inerting significantly reduces the formation of slag on the melt surface[2].

RESULTS

It is sometimes difficult to tell small pinholes from small inclusions, so many foundries lump these two together and classify them as "holes". The data presented use this broader classification.

Figure 2 presents information on rejects due to holes for various grades. In all cases the comparisons between air-melted and LBI heats are for identical parts and identical alloys. As shown, the rejects due to holes in decreased when LBI is used.

The alloys Waspaloy*, HX* and Alloy X* represent proprietary alloys that are close to the compositions of the named alloy.

DISCUSSION

LBI results in reductions in reject rates due to holes.

Decreases in hole reject levels in the iron - chromium grades are not as large or as consistent as in the nickel - chromium grades. This is possibly due to the more sensitive nitrogen thermodynamics in nickel alloys when compared with iron alloys.

For example, at 2850°F, an alloy containing 18% chromium, 2% molybdenum and 1% tungsten in equilibrium with air would contain 3030 ppm nitrogen if it were nickel-base and 2750 ppm if it were iron-base. This difference in nitrogen solubility, and hence nitrogen bubble evolution during solidification is one of the reasons why air-melt reject rates due to holes, shown in Figure 3, are usually much higher for nickel-chromium grades than iron-chromium grades. Undoubtedly, part design plays an important role in reject rates, but the trend is quite clear.

Hydrogen is also a source of porosity. Some alloys must be degassed before casting to avoid porosity. LBI has been shown to reduce the amount of hydrogen present in metals by as much as 75%[2].

Statistical Analysis

The data in Figure 2 represent average levels. The number of rejects due to holes is divided by the number of parts made. Many foundries do not routinely track parts specifically by heat, so this average information is often the only type available.

However, there can be considerable differences in reject rates from heat to heat. Random variations may make a change in a process appear better or worse than it really is. A problem during a work shift can result in poor performance during that time. For instance, interrupted casts due to crane difficulties is a systematic effect that would skew the data for that period. (This is the basis of control and cumulative sum charts which would show this problem immediately.) over time, the bad heats would be averaged into the entire data base.

In order to use tests of statistical significance, it is important to be able to estimate the variance of the data being compared. Pooled estimates of variance can be used. These are weight averaged calculations of the variance. The variance is obtained from heat by heat data.

The variance and average can be calculated for the Alloy X* data. The reductions in rejects by hole defects for Alloy X* are statistically significant at the 98% confidence level. This says that we are 98% certain that the observed differences are real and not the result of natural variation in the process.

It is simple enough to discuss averages and perhaps standard deviations, but if the underlying data is not from a normal (Gaussian) population, then the usual conventions, (for example, 68% of the data from the population will be within ± one standard deviation of the mean), may not apply.

An easy way to tell if a sample set follows a normal distribution is to plot the data on normal cumulative probability paper[5]. If the data appears to be a reasonably straight line when plotted on normal probability paper, the data comes from a normal distribution.

This plotting can be performed in a spreadsheet program by using the numerical method given by Abramowitz and Stegun[6]. The data are ranked in ascending or descending order. Each point is given a cumulative probability based on its rank. The cumulative probability is:

$$p = rank \times \left(\frac{1}{N+1} \right)$$

where N is the total number of data points. The cumulative where N is the total number of data points. The cumulative probability axis (x-axis) is

$$x_p = t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} + \in (p)$$

where

$$t = \sqrt{\ln \frac{1}{p^2}}$$

and

$$\left| \in (p) \right| \langle 4.5 \times 10^{-4}$$

and

$$\begin{array}{lllllll} c_0 & = & 2.515517 & \quad & d_1 & = & 1.432788 \\ c_1 & = & .802853 & & d_2 & = & .189269 \\ c_2 & = & .010328 & & d_3 & = & .001308 \end{array}$$

Available data on rejects due to holes by heat are plotted in Figures 4 and 5. We can conclude that hole rejects are normally distributed. As shown in the figures, there is considerable variation in reject rates under normal operations.

In most cases, the LBI protected heats are in the low ends of the distributions. This is a good indication that LBI is a factor in lowering the reject rates. The LBI points are also grouped together. This may be an indication that LBI reduces the amount of variability in the process.

Why are hole rejects normally distributed? If we take one source of hole rejects, dissolved gas, there should be some characteristic level of dissolved gas in a heat of material. This characteristic level will form a certain amount of porosity, which will vary with a wide variety of factors which are essentially random (as opposed to systematic). A process with a "target" level and random variation about this target will create a normal distribution.

ECONOMIC BENEFITS

The reduction in rejects translates into savings to the foundry. Most of the parts produced during these tests were smaller parts: 0.05 to 5 pounds. In a 500 pound induction furnace, this works out to 100 to 5000 (subtracting gates and risers) parts per heat. At several dollars per part selling price, there are substantial benefits, especially for the higher cost alloys.

For instance, the reject rate for air-melted Alloy X* is about 30%. At 1000 parts per heat, the rejects would be 300 parts. The LBI-protected reject rate is about 17%, so the rejects are 170. There are 130 more parts available when LBI is used. At $5 per part selling price, there is a benefit of $650, not including gas costs.

This does not include the amount of reworks. In one case, the percentage of air-melted parts needing rework was 7.9%. For LBI-protected parts, the rework rate was 0.09%. Reworks can be a substantial portion of costs, so the savings here can also be substantial.

Another factor is reverted material. Some foundries use certified alloys once and resell scrap material back to the supplier. With reduced dissolved gas contents, reduced alloy loss and reduced slag, the reverted material might be reusable.

SUMMARY

Laminar Barrier Inerting's benefits for dissolved gases and slag reduction are well documented. What is shown here is that reject rates due to holes decrease when LBI is used. The most significant reduction is in alloys that are sensitive to dissolved gases. Rejections by hole defects appear to be normally distributed. Savings to foundry operations are possible.

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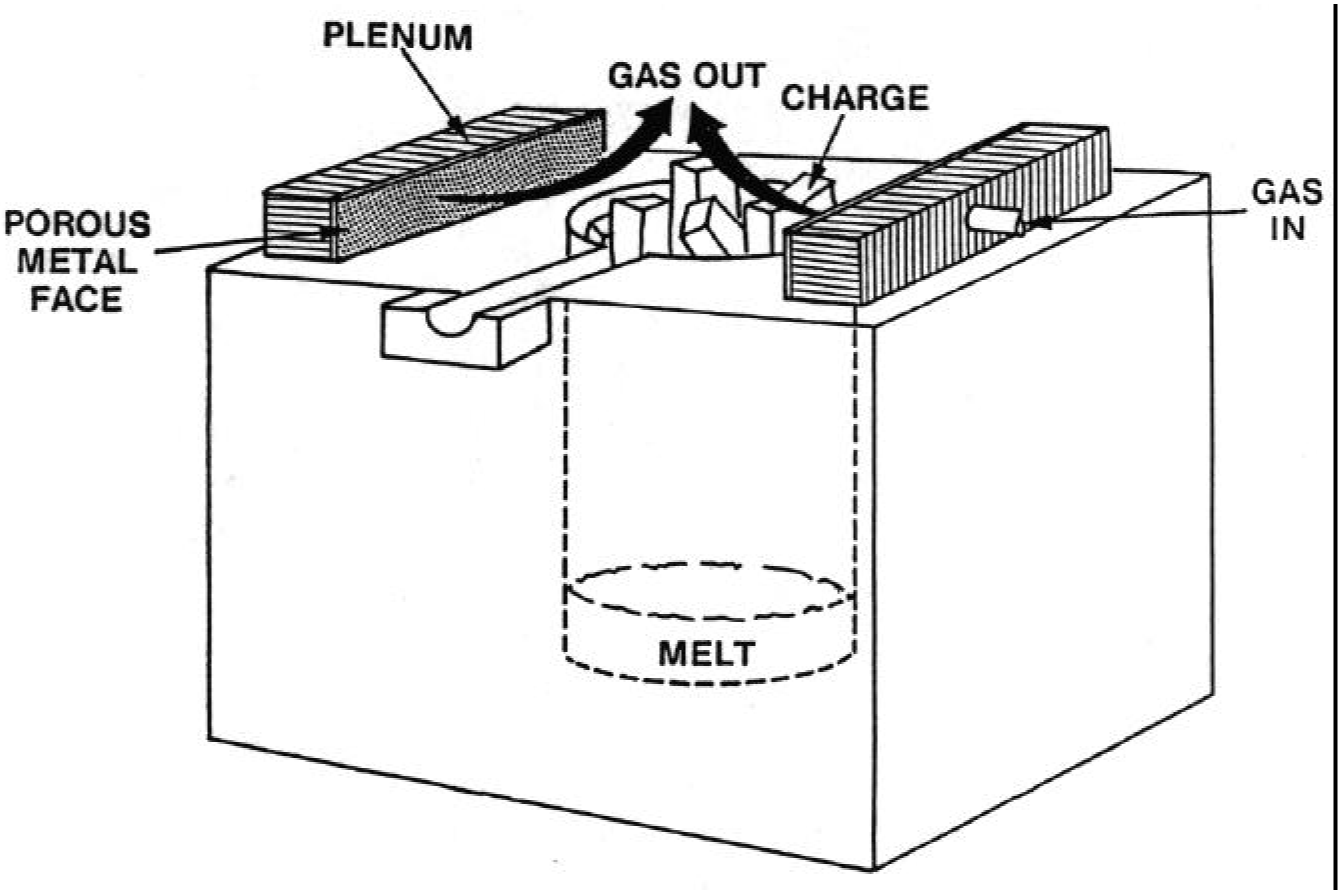


Figure 1 - Laminar Barrier Inerting on an Induction Furnace.

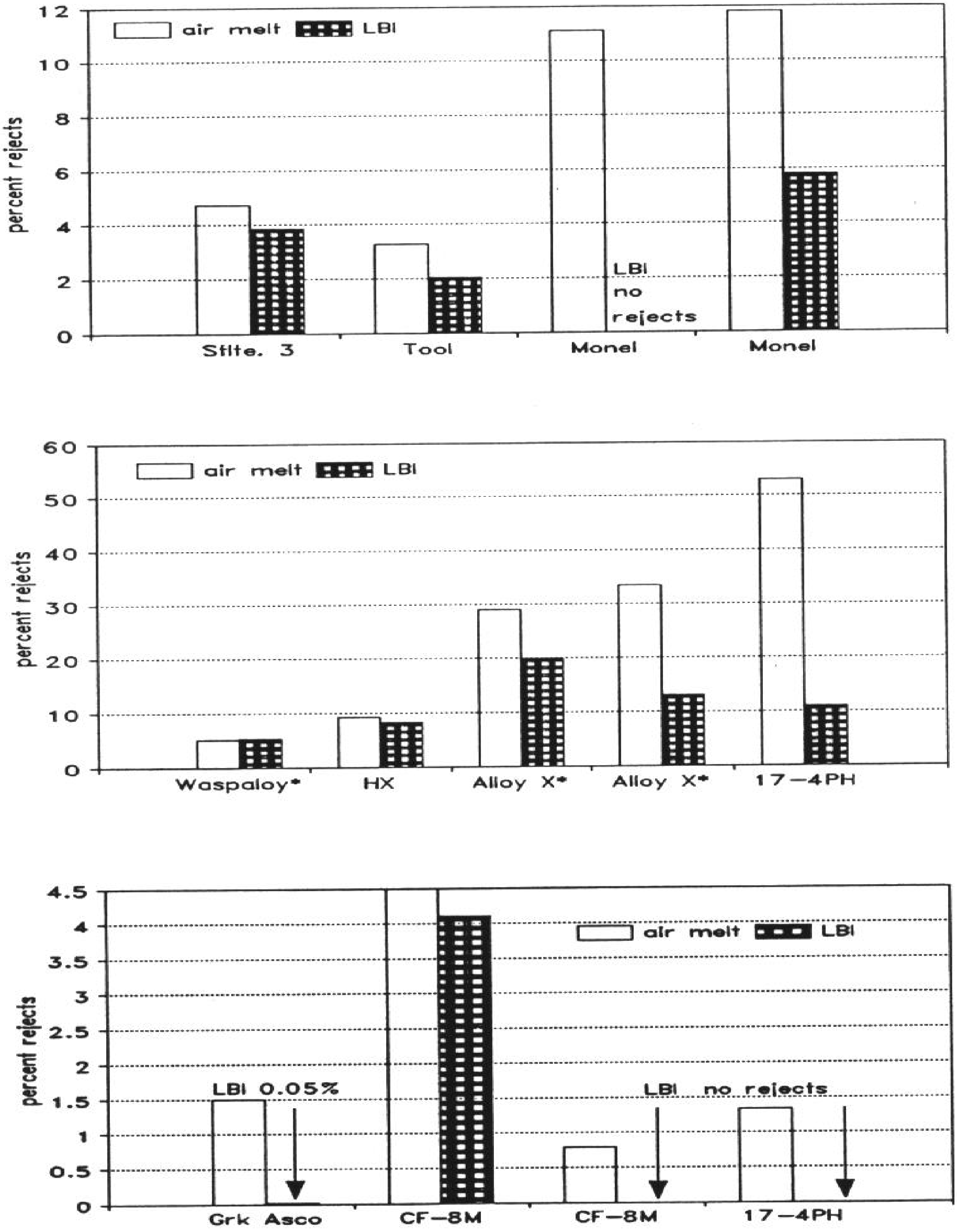


Figure 2 - Rejects due to holes, cobalt, tool, Monel, iron-based and nickel-based grades. Comparisons are between identical parts and alloys. Air-melt on left side of each pair, LBI on right.

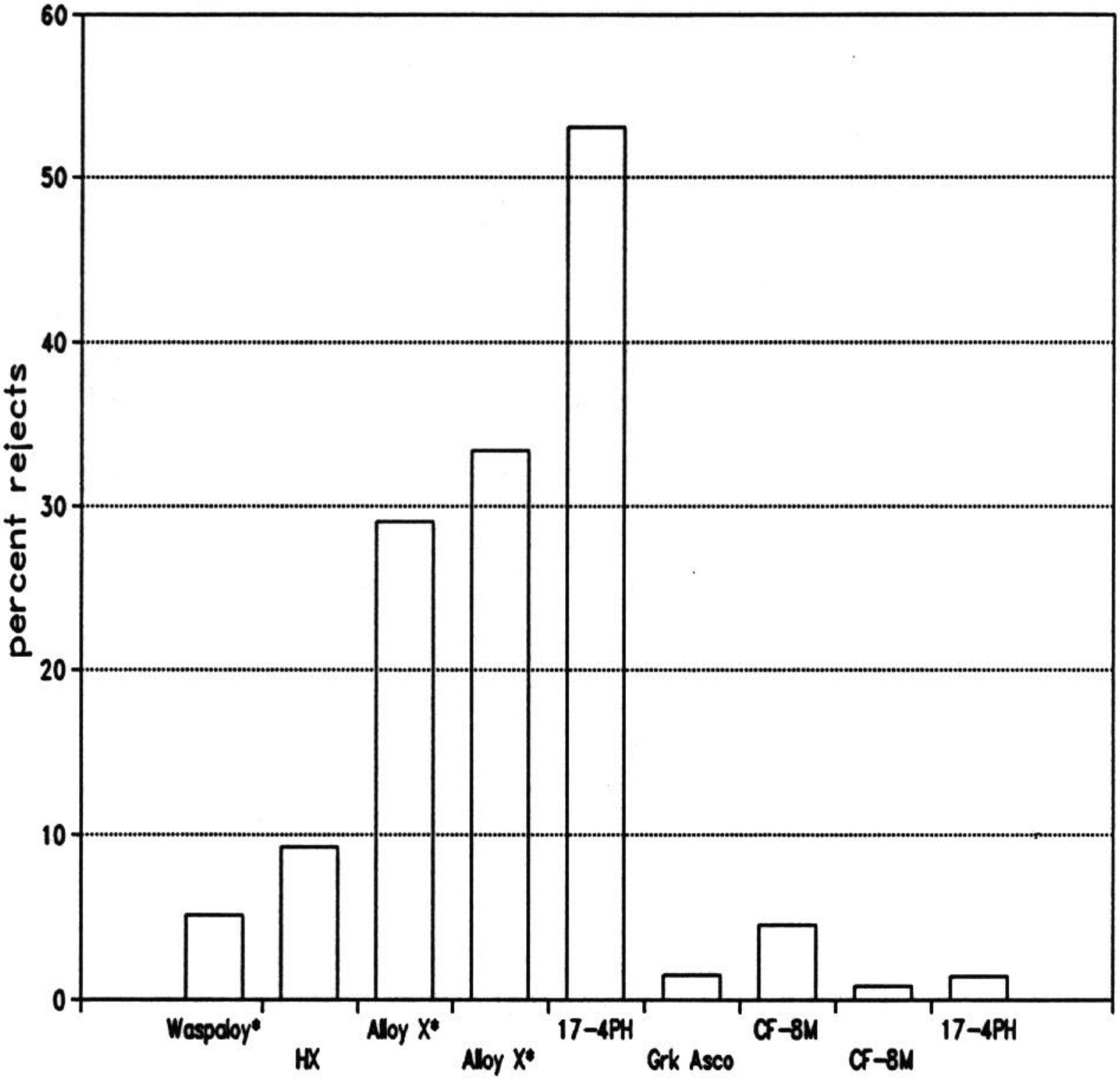
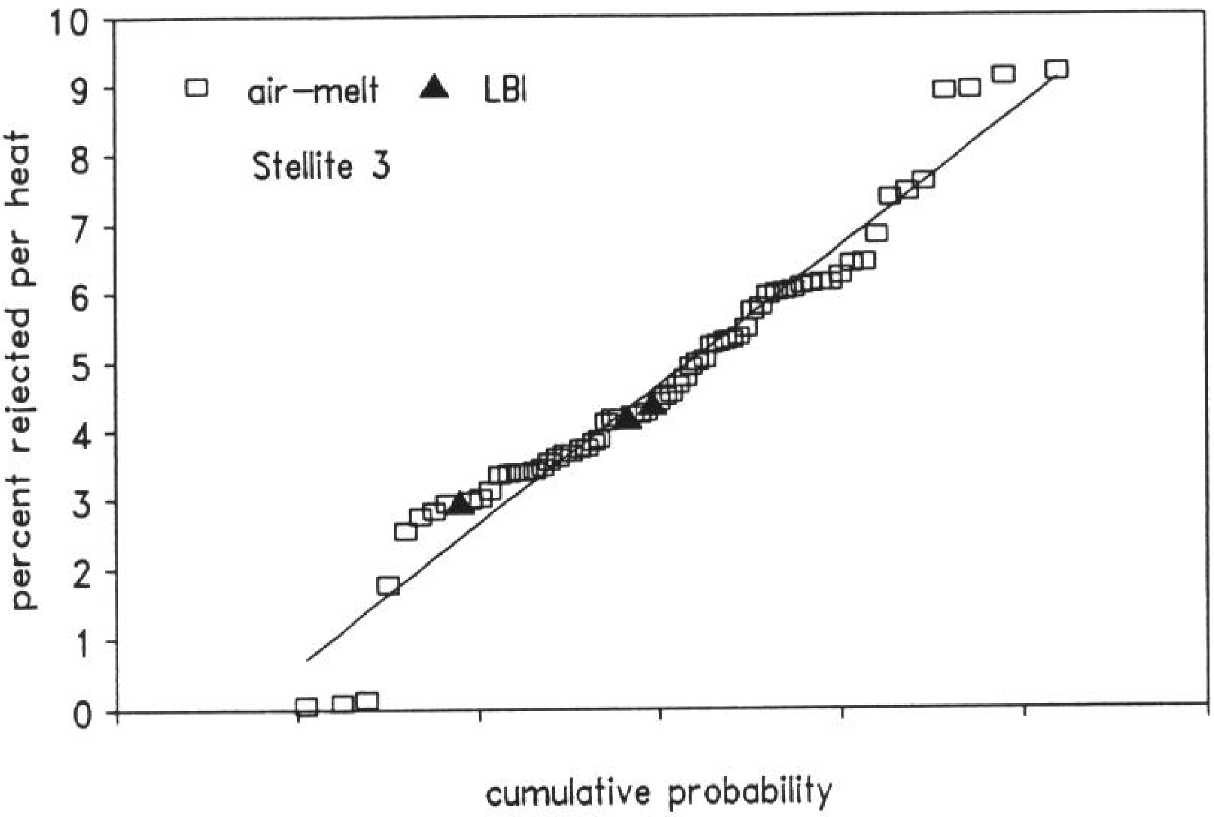


Figure 3 - Rejects by hole defects, comparison between air-melted iron-based and nickel-based heats.



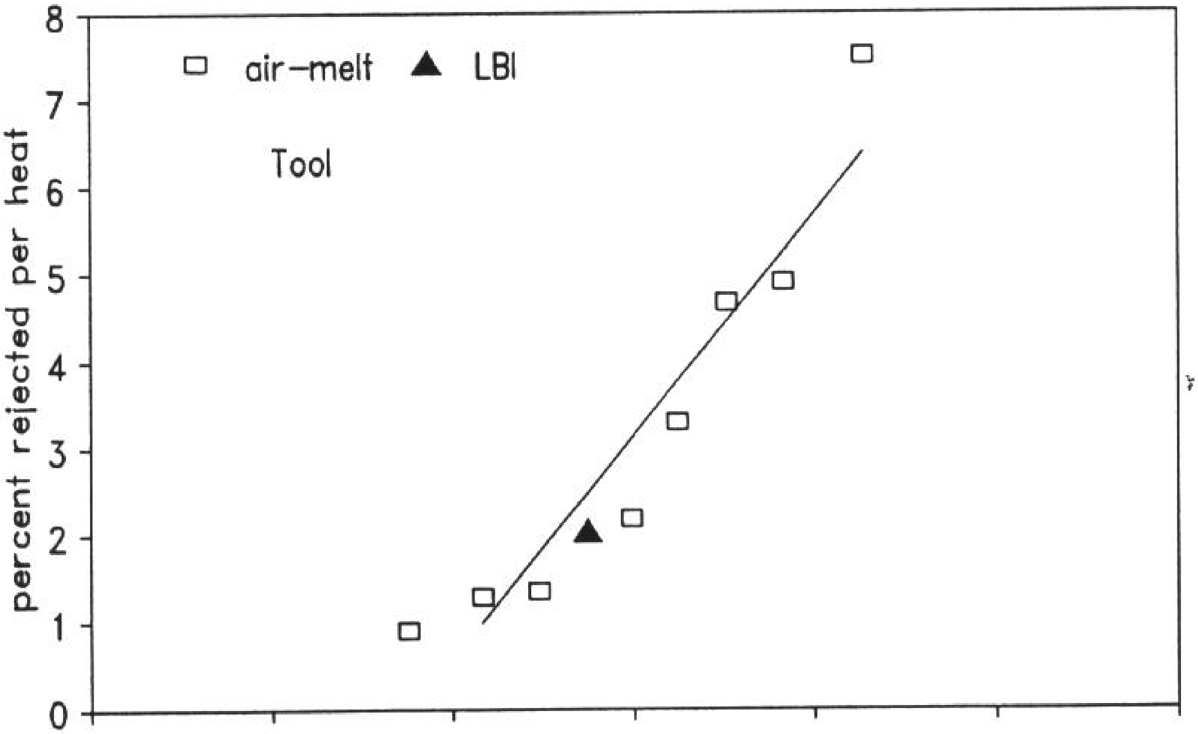


Figure 4 - Normal probability plots for rejects by hole defects; cobalt and tool alloys. The data probably come from normal distributions.

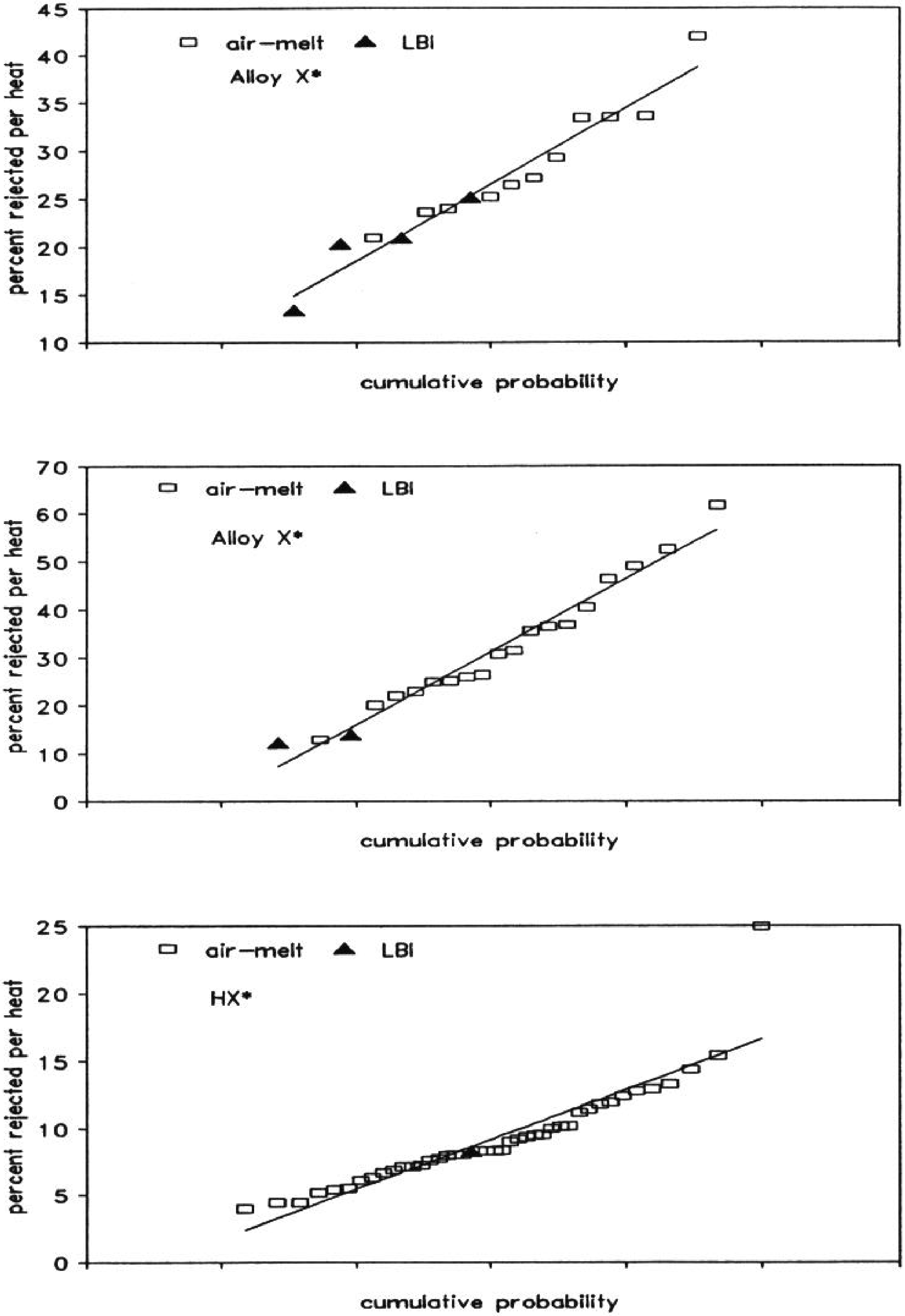


Figure 5 - Normal probability plots for rejects by hole defects for nickel-base alloys. The data probably come from normal distributions.