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JBK-75 MICROSTRUCTURE SPECIFICATION RECOMMENDATION

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SUBJECT DESCRIPTORS

Stainless Steel
JBK-75 (A-286M)
Microcleanliness
Grain Size

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JBK-75 MICROSTRUCTURE SPECIFICATION RECOMMENDATION

A. W. Brewer

Abstract. Since the ASTM-E-45 standard for microcleanliness is not applicable to superalloys like JBK-75 stainless steel, Rocky Flats should adopt the Ladish microcleanliness standard (APML Cleanliness Classification of High Temperature Alloys Chart, 1971), as a guide for setting material acceptance specifications for JBK-75. Inclusion ratings of S-2, N-2, C-2, and M-2 should be acceptable. The microstructure should have a grain size of 5 or finer, but not smaller than 9, and microsegregation (banding) should be kept to a minimum.

INTRODUCTION

Superalloys such as JBK-75 (Modified A-286), exhibit a wide variety of non-metallic and inter-metallic inclusions unique to this class of stainless steel. The predominance and morphology of these inclusions are not normally observed in austenitic stainless steels, such as Type 304, for which the existing acceptance standards were developed. Their occurrence is primarily dependent upon alloy chemistry and processing parameters from the melt through the forged product. Total elimination of such constituents is impossible. However, the inclusions and microsegregation can be minimized during early manufacturing processing.

Alloys like JBK-75 contain strong carbide and nitride formers, such as titanium carbide (TiC) and titanium carbide/nitride (TiC/N). Complex carbide/nitride compounds can have a deleterious effect on the mechanical properties. Although their occurrence cannot be completely avoided, their quantity, size, and distribution can be controlled by alloy chemistry, melting practice, and ingot breakdown.^{1, 2}

The purpose of this report is to propose a level and distribution of inclusion content and grain-size range to be included in any quality standard for acceptance of forging stock. The ASTM-E-45 standard for determining the inclusion content of steel is not directly applicable to superalloys like JBK-75, since carbide and carbonitride inclusions are not covered in the specification. In addition, since the carbides can have an adverse effect on mechanical properties, the need to define a material-acceptance criteria based on distribution of inclusions is important. This could be done by using a photomicrographic rating system based on specific distribution of carbide-type inclusions. The intent of this report is to provide guide lines for a rating system based on historical information for establishing such specifications for JBK-75. The information is discussed in two parts, inclusions and microstructure.

DISCUSSION

Inclusions

Data from four heats of JBK-75 stainless steel, used in production of parts, have been examined. All heats were of the double melt process, vacuum induction melt-electroslag remelt (VIM-ESR), or vacuum induction melt-vacuum arc remelt (VIM/VAR), which is common practice for superalloys. Chemical analysis of each heat is tabulated in Table I. The material from this double melt process is relatively free of the normal inclusions rated by the ASTM-E-45 standard, i.e., aluminates, oxides, sulfides, and silicates. For example, these types of inclusions rarely approach the least severe rating at a 100X magnification.

TABLE I. Chemistry Weight Percent Values by Average of Vendor Analysis

Alloy	Heat No.	Melting Practice	Nitrogen	Carbon	Phosphorus	Sulfur	Silicon	Manganese	Nickel
^a JBK-75	H-926	VIM/ESR	^b NA	0.020	0.005	0.003	0.04	<0.01	30.85
JBK-75	H-927	VIM/ESR	0.0036	0.024	0.004	0.002	0.03	0.05	30.09
^a JBK-75	2448	VIM/ESR	0.0038	0.019	0.005	0.003	< .01	0.02	30.00
JBK-75	93491	VIM/VAR	0.002	0.015	0.002	0.002	0.01	0.003	29.4

Alloy	Heat No.	Melting Practice	Chromium	Vanadium	Molybdenum	Boron	Aluminum	Titanium	Aluminum/Titanium
^a JBK-75	H-926	VIM/ESR	14.45	0.30	1.28	<0.001	0.27	2.23	0.121
JBK-75	H-927	VIM/ESR	14.28	0.30	1.32	<0.001	0.26	2.12	0.123
^a JBK-75	2448	VIM/ESR	14.35	0.33	1.36	<0.001	0.31	2.18	0.142
JBK-75	93491	VIM/VAR	14.1	0.41	1.2	<0.005	0.30	2.2	0.136

^aLadle Analysis
^bNA - Not Available

Since JBK-75 is a precipitation-strengthened alloy, precipitating γ' Ni₃ (Al, Ti), the titanium (Ti) and aluminum (Al) composition in the matrix needs to be controlled. Previous work¹ has shown that the inclusions in JBK-75 are of the TiC/Ti-carbonitride type. Therefore, the size and distribution of these inclusions becomes important in controlling the available Ti to form the γ' strengthening phase. As these inclusions become larger and more numerous, the Ti composition in the matrix is lowered, and the hardenability of the alloy is decreased. This results in different age hardening response, making the thermomechanical process less effective in obtaining consistent properties in the fabricated product.

Since the ASTM specification does not consider carbide-type inclusions, some alternate method

of rating size and distribution of carbides must be used. Two such methods have been developed; one method by Cameron Iron Works (CIW),³ and one by the Ladish Company.⁴ The procedures are similar, and they are used to quantitatively rate carbides as stringers, networks, clusters, or a mixture of the three.

The CIW method is numerical and graphical; however, their graphical representation was not available. The Ladish method is graphical, and is the method recommended for Rocky Flats to adopt for rating inclusions in superalloys. It is more economical for a laboratory to compare a photomicrograph with a graphic representation than to measure and count individual carbides to extract a numerical representation of the cleanliness. Tables II and III show reproductions of both methods.

TABLE II. Nonmetallic Concentrations by Distribution
Type. 0.030-Inch by 0.040-Inch Field. Magnification 100X.

Severity Level	Type A Stringer ←	Type B Cluster (Length)	Type C Chain →	Type D Background (No. of Particles)	Type CX Complex (Length)
1/2	0.005 in. (0.0127 cm.)	0.005 in. (0.0127 cm.)	0.007 in. (0.01778 cm.)	2	0.007 in. (0.01778 cm.)
1	0.010 in. (0.0254 cm.)	0.010 in. (0.0254 cm.)	0.015 in. (0.0381 cm.)	5	0.015 in. (0.0381 cm.)
1-1/2	0.017 in. (0.04318 cm.)	0.017 in. (0.04318 cm.)	0.022 in. (0.05715 cm.)	7	0.022 in. (0.05715 cm.)
2	0.025 in. (0.0635 cm.)	0.025 in. (0.0635 cm.)	0.030 in. (0.0762 cm.)	9	0.030 in. (0.0762 cm.)
2-1/2	0.037 in. (0.09525 cm.)	0.037 in. (0.09525 cm.)	0.042 in. (0.1079 cm.)	13	0.042 in. (0.1079 cm.)
3	0.050 in. (0.1270 cm.)	0.050 in. (0.1270 cm.)	0.055 in. (0.1397 cm.)	18	0.055 in. (0.1397 cm.)
3-1/2	0.070 in. (0.1778 cm.)	0.065 in. (0.1651 cm.)	0.0775 in. (0.1968 cm.)	24	0.0775 in. (0.1968 cm.)
4	0.090 in. (0.2286 cm.)	0.080 in. (0.2032 cm.)	0.100 in. (0.2540 cm.)	30	0.100 in. (0.2540 cm.)
4-1/2	0.110 in. (0.2794 cm.)	0.100 in. (0.2540 cm.)	0.125 in. (0.3175 cm.)	40	0.125 in. (0.3175 cm.)
5	0.130 in. (0.3302 cm.)	0.120 in. (0.3048 cm.)	0.150 in. (0.3810 cm.)	51	0.150 in. (0.3810 cm.)
5-1/2	0.155 in. (0.3937 cm.)	0.136 in. (0.3454 cm.)	0.1875 in. (0.4762 cm.)	70	0.1875 in. (0.4762 cm.)
6	0.180 in. (0.4572 cm.)	0.152 in. (0.3861 cm.)	0.225 in. (0.5715 cm.)	90	0.225 in. (0.5715 cm.)

TABLE III. APML Cleanliness Classification of High Temperature Alloys. The Ladish Company. Magnification 100X.

Legend

- S – Intermetallic and/or metallic stringer segregation.
 N – Intermetallic and/or metallic network segregation.
 C – Intermetallic and/or metallic cluster segregation.
 M – Intermetallic and/or metallic mixture:
 stringer, network and cluster segregation.

1 through 6 – Level of inclusion severity, increases as numbers increase.

Table IV summarizes the results of Quality Acceptance qualification of JBK-75 alloys from the four heats used to date. Data from each heat are summarized according to bar size, the average worst area for inclusions as rated by the Ladish method and ASTM-E-45 Plate I, and the grain size.

It was hoped that mechanical properties of the forged material from the heats could be compared with the inclusion content, thereby obtaining some idea of the effect of inclusion on mechanical properties. However, the forging parameters have been changed throughout to improve properties, so a comparison of inclusions to forging properties, is not meaningful at this time. A study to determine the effect that a specific inclusion content has on mechanical properties of forgings is needed.

Although a specific recommendation cannot be made for an inclusion level for a Quality Acceptance specification for JBK-75 alloy, an empirical recommendation based on past experience with other superalloys would indicate that while an inclusion level of S-2, N-2, C-2, or M-2, per the Ladish chart would be acceptable, a higher level of 3's would be questionable.⁵ The author feels that material vendors, using proper processing procedures, could meet this requirement with a reasonable degree of economy. It should be noted that the Ladish Company is currently utilizing their rating chart as an acceptance criteria for material rejection. For example, for A-286, they have adopted the following rating levels: 2 – Acceptable, 3 – Review, and 4 – Rejectable.⁵ Figures 1 through 4 are 100X magnification photomicrographs of inclusions typical of each heat.

TABLE IV. Quality Acceptance Qualification of JBK-75 Stainless Steel Alloys

Heat No.	Bar Size	Inclusions (Ladish)	Rating (ASTM)	Grain Size (STTM)	Quality Acceptance Control Number	Metallurgical Laboratory Number
2448	4 in.	S-2-1/2	4D Heavy	60% 4 40% 5-8	104999	2349
926	1.25 in.	S-3	4B Heavy	8 and finer	104983	2227
927	4.5 in.	M-1	3D Heavy	50% 4 50% 9	104993	2278
93491	5 in.	S-2	4D Heavy	50% 6 50% 1	105168	2599

FIGURE 1. Photomicrograph from Heat 927 showing stringer-type titanium carbide/nitride inclusions in 5-inch diameter bar stock. The inclusions rated by the Ladish method would be M-2. Magnification 100X.

FIGURE 2. Photomicrograph from Heat 2448, 4-inch diameter bar stock with stringer-type inclusions. An inclusion rating by Ladish would be S-2 1/2. Magnification 100X.

Microstructure

The strength of superalloys is dependent upon grain size, therefore, control of grain size becomes important. Excessively large grains reduce tensile and yield properties.⁶ Microsegregation, sometimes

seen as banding, also has a deleterious effect on the mechanical properties. Grain size and banding have serious effect on the forgability of JBK-75 alloy, particularly with the High Energy Rate Forge (HERF) process.⁷

FIGURE 3. Photomicrograph from Heat 926, 1-1/4-inch diameter bar stock having a Ladish rating of S-3. Magnification 100X.

FIGURE 4. Photomicrograph from Heat 93491, 4-inch diameter bar stock having a Ladish rating of S-2. Magnification 100X.

FIGURE 5. Photomicrograph from Heat 93491, 4-inch diameter bar stock showing a small amount of banding. Grain size is about 60 percent 7's and 40 percent 3's. Magnification 100X.

Again, due to the lack of data on JBK-75, proposed grain size and banding specifications will be empirical recommendations. It is known that very large grains (ASTM 00 to 2) reduce forgeability and give inconsistent results in mechanical properties, particularly if the grain size is duplexed (large and small grains).⁷ Large grains are more difficult to refine during forging, especially in areas of minimal work. Therefore, the optimum grain size for bar stock and plate would be ASTM-5 or finer. A small amount of duplexing could be tolerated within a small range of grain sizes.

Banding in the microstructure should be kept to a minimum. Chemical microsegregation, resulting from banding, causes duplexing of microstructure and nonuniform properties in the finished product. Figures 5 through 8 show examples of microstructures found in JBK-75. Presently, no method exists for rating the severity of banding.

If a product adhering to the above recommendations could be economically obtainable from the vendors of JBK-75 and other superalloys, products made from the alloys should have more consistent properties and would be more economical to process than at present.

CONCLUSIONS

The standard rating system should use the Ladish APML Cleanliness Classification of High Temperature Alloys Chart, 1971, for inclusion rating of JBK-75 and other precipitation-hardened alloys.

A rating of S-2 or M-2 should be acceptable to vendors. Heavier ratings would be questionable in that forgeability and mechanical properties would suffer.

Grain size on bar and plate stock should be between ASTM 5 and 9.

FIGURE 6. Photomicrograph from Heat 926, 1-1/4-inch diameter bar stock with small grain size (8 or finer), with little banding. This microstructure would be acceptable. Magnification 100X.

FIGURE 7. Photomicrograph from Heat 2448, 4-inch diameter bar stock showing a duplex grain structure, 60 percent 5 to 8, and 40 percent 4 or larger. This microstructure would not be desirable as forging stock. Magnification 100X.

FIGURE 8. Photomicrograph from Heat 927, 5-inch diameter bar stock showing moderate banding. Grain size varied throughout the bar, but typically was about 3 or larger. This microstructure would not be desirable as forging stock. Magnification 100X.

Microsegregation or banding should be kept to a minimum.

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