



AEROSPACE STANDARD

AS5491™**REV. D**

Issued	2000-12
Revised	2007-11
Reaffirmed	2013-10
Stabilized	2019-07

Superseding AS5491C

Calculation of Electron Vacancy Number in Superalloys

RATIONALE

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1. SCOPE

1.1 Purpose

This SAE Aerospace Standard (AS) establishes a uniform procedure for calculation of electron vacancy numbers in superalloys. It is intended for use by suppliers of raw materials and parts, typically castings, for which control of electron vacancy number is required by the raw material specification.

1.2 Application

This procedure has been used to estimate the potential for alloy phase instability by calculation of the density of electrons per atom in nickel-based superalloys.

1.3 Background

1.3.1 Complex, highly alloyed superalloys have been observed, for some alloy chemistries and under certain conditions, to form precipitated phases which can adversely affect strength and ductility. These phases, typically of a crystalline structure known as topologically close-packed, or TCP, appear after extended exposure at temperatures in the range from 1300 to 1650 °F (704 to 899 °C). Such phases include sigma (σ), mu (μ), or Laves. Their tendency to precipitate from the alloy matrix has been related by researchers such as Boesch and Slaney (see 2.1) and Woodyatt, et al. (see 2.2) to the density of electrons per atom as expressed by the electron vacancy number N_v , as shown in Equation 1, as follows:

$$N_v = \sum_{i=1}^n m_i (N_v)_i \quad (\text{Eq. 1})$$

where:

N_v is the electron vacancy number for the alloy

m_i is the atomic mass fraction of the i th element in the alloy composition, and

$(N_v)_i$ is the electron vacancy number of the i th element.

Determination of the electron vacancy concentration requires an understanding of the phases which precipitate in superalloys as well as the sequence in which they form in the gamma matrix. In general, this sequence is (a) the precipitation of borides, (b) the precipitation of carbides, and (c) the formation of gamma prime. When these phase reactions are considered, and adjustments made to the composition to take them into account, the residual matrix composition may be determined. From that residual matrix the electron vacancy number is then calculated.

1.3.2 The sequence of precipitation of strengthening phases is addressed as follows:

1.3.2.1 Nickel, chromium, titanium, and molybdenum form a boride as $(Mo_{0.5}, Ti_{0.15}, Cr_{0.25}, Ni_{0.10})_3B_2$.

1.3.2.2 All carbon is assumed to form carbides of the type MC and $M_{23}C_6$. It is assumed that MC carbides take half the carbon, reacting in sequence with tantalum, columbium, zirconium, titanium, and vanadium. The remaining carbon then reacts with chromium, molybdenum, and tungsten to form $Cr_{21}(Mo,W)_2C_6$.

1.3.2.3 Gamma prime is formed from the remaining aluminum, titanium, hafnium, columbium, tantalum, 50 percent of the original amount of vanadium, and 3 percent of the original amount of chromium by combining with three times that total in nickel, i.e., $Ni_3(Al, Ti, Cb, Hf, Ta, 0.5V, 0.03Cr)$.

1.3.2.4 The remaining chromium content is adjusted for that lost due to formation of borides, carbides, and gamma prime.

1.3.2.5 The remaining nickel content is adjusted for that tied up in boride and gamma prime formation.

2. REFERENCES

2.1 W. J. Boesch and J. S. Slaney: Metal Progress, July 1964, Vol. 86, No. 1, pp 109-111.

2.2 L. R. Woodyatt, C. T. Sims and H. J. Beattie, Jr.: Transactions of the Metallurgical Society of AIME, April, 1966, Volume 236, pp 519-527.

3. TECHNICAL REQUIREMENTS

3.1 Calculation of N_v

3.1.1 N_v shall be calculated in the following order:

3.1.1.1 Conversion of weight percentage to atomic percentage for each element

3.1.1.2 Calculation of boron and carbide precipitation

3.1.1.3 Calculation of gamma prime precipitation

3.1.1.4 Calculation of the residual gamma matrix composition

3.1.1.5 Determination of electron vacancy number, N_v

3.1.2 It may be helpful to set up a matrix similar to Table 1 to facilitate recording compositions through the process of electron vacancy number calculation.