



AEROSPACE STANDARD

AS7045™

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Residual Stress Measurement and Classification,
Metallic Structural Alloy Products and Finished Parts

RATIONALE

AS7045 standardizes methods for defining, quantifying, and classifying residual stress in metallic structural alloy products and finished parts.

1. SCOPE

1.1 Purpose

The purpose of this standard is to provide uniform methods for defining, quantifying, and classifying the residual stress in metallic structural alloy products and finished parts. These stresses may exist within a single element, or they may be the result of a joining process. Such quantification and classification may be required when residual stresses within mill stock or preforms can impact further in-process distortion during machining or other processes, and when residual stresses within finished components can impact final mechanical properties and performance (especially strength, durability, and fracture performance).

1.2 Application

The methods for residual stress assessment in this standard are applicable in the prediction and measurement of fabrication process induced residual stresses, joining process induced residual stresses, and engineered residual stresses. Application of the methods in this standard is limited to metallic structural alloy products and finished parts made from structural alloy products (see 2.9.9), such as alloys of aluminum, titanium, nickel, and steel.

1.3 Classification

Structural alloy products and finished parts made from such products shall be classified with respect to the category and general magnitude of residual stress found to exist in such products or parts.

1.3.1 Categories

Category 1: Bulk Residual Stress (Near-Zero Controlled Residual Stress)

Bulk residual stresses are typically material production, process, or forming stresses and are generally bulk in nature (i.e., distributed over the part volume). Category 1 residual stresses can be managed first by applying post-production processes, such as mechanically cold working or thermally stress relieving to reduce or eliminate them; and second, by assessing the value of residual stress at one or more critical locations and demonstrating by analysis or testing that if the assessed residual stress is within a known range (Class), then the product or part will meet its design performance requirements. While the objective is to identify and limit the presence of detrimental tensile residual stresses, there are scenarios in which the objective could be to control compressive residual stress because compression at one location is an indicator of equilibrating tension at another location.

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Category 2: Joining Residual Stress (Tensile Controlled Residual Stress)

Joining residual stresses are typically generated by processes such as welding (arc, electron beam, laser, pressure, or friction, etc.), thermal or kinetic deposition processes, soldering, etc., and are typically confined to the vicinity of the joint or deposit. Category 2 residual stresses can be managed first by applying post-weld or post-deposition processes, such as heat-treating or cold working to reduce or eliminate the residual stresses; and second, by assessing the value of residual stress at one or more critical locations and demonstrating by analysis or testing that if the assessed residual stress is within a known range (Class), then the product or part will meet its design performance requirements. The objective is to identify and limit the presence of detrimental tensile residual stresses.

Category 3: Engineered Residual Stress (Compressive Controlled Residual Stress)

Engineered residual stresses are typically installed using controlled plastic deformation at specific critical locations within a product or part; they are generally localized in nature. Examples include low plasticity burnishing, conventional shot peening, laser shock peening, and hole cold expansion. Category 3 residual stresses can be managed first by ensuring that the installation process is properly executed; and second, by assessing the value of residual stress at one or more critical locations and demonstrating by analysis or testing that if the assessed residual stress is within a known range (Class), then the product or part will meet its design performance requirements. The objective is to ensure that sufficient, beneficial compressive residual stress has been installed.

Category 4: Specified Target Residual Stress (RS_{target})

This is a general category in which the cognizant engineering organization (CEO) defines a target value of residual stress, and the product or part is classified according to how close in magnitude the assessed value of residual stress is to the target value. This category can be used when the required target value of residual stress does not match any of the implied target values of the other categories ($RS_{\text{target}}=0$ for Categories 1 and 2, $RS_{\text{target}}=-F_{\text{ty}}$ for Category 3). This category can also be used for any residual stress not characterized as Category 1, 2, or 3; examples of which are machining stresses or coating application (thermal or chemical) stresses which tend to be very localized in nature.

1.3.2 Acceptance Class

1.3.2.1 Residual stress acceptance classes are defined in Table 1. Class E is defined to facilitate monitoring residual stress at locations of interest without any requirements for control.

Table 1 - Residual stress category and class

Category	Class	Tolerance Band ⁽¹⁾
1	A	$ RS_{\text{assess}} \leq 5\% F_{\text{ty}}$
	B	$5\% F_{\text{ty}} < RS_{\text{assess}} \leq 20\% F_{\text{ty}}$
	C	$20\% F_{\text{ty}} < RS_{\text{assess}} \leq 50\% F_{\text{ty}}$
	D	$ RS_{\text{assess}} > 50\% F_{\text{ty}}$
	E	Report requirement only
2	A	$RS_{\text{assess}} \leq 10\% F_{\text{ty}}$
	B	$10\% F_{\text{ty}} < RS_{\text{assess}} \leq 25\% F_{\text{ty}}$
	C	$25\% F_{\text{ty}} < RS_{\text{assess}} \leq 50\% F_{\text{ty}}$
	D	$RS_{\text{assess}} > 50.1\% F_{\text{ty}}$
	E	Report requirement only
3	A	$RS_{\text{assess}} \leq -80\% F_{\text{ty}}$
	B	$-80\% F_{\text{ty}} < RS_{\text{assess}} \leq -50\% F_{\text{ty}}$
	C	$-50\% F_{\text{ty}} < RS_{\text{assess}} \leq 0\% F_{\text{ty}}$
	D	$RS_{\text{assess}} > 0$
	E	Report requirement only
4	A	$ RS_{\text{assess}} - RS_{\text{target}} \leq 5\% F_{\text{ty}}$
	B	$5\% F_{\text{ty}} < RS_{\text{assess}} - RS_{\text{target}} \leq 20\% F_{\text{ty}}$
	C	$20\% F_{\text{ty}} < RS_{\text{assess}} - RS_{\text{target}} \leq 50\% F_{\text{ty}}$
	D	$ RS_{\text{assess}} - RS_{\text{target}} > 50\% F_{\text{ty}}$
	E	Report requirement only

⁽¹⁾ F_{ty} is defined as tensile yield strength.



1.3.2.2 RS_{assess} is the measured or modeled residual stress at a specified location and in a specified orientation in the structural alloy product or finished part. RS_{assess} is assessed as stated in 3.2. Since many measurement techniques produce multiple readings at a point, or along a line or over a plane, it is necessary to choose a single value of characteristic residual stress to be used for classification. Tables 2 and 3 provide a listing of the major residual stress measurement techniques, along with suggested definitions for the characteristic residual stress for each.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AS7766 Terms Used in Aerospace Metals Specifications

AS9100 Quality Management Systems - Requirements for Aviation, Space, and Defense Organizations

HS-784 Residual Stress Measurement by X-Ray Diffraction

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM E837 Test Method for Determining Residual Stresses by the Hole-Drilling Strain-Gage Method

ASTM E915 Test Method for Verifying the Alignment of X-Ray Diffraction Instruments for Residual Stress Measurement

ASTM E1426 Test Method for Determining the X-Ray Elastic Constants for Use in the Measurement of Residual Stress Using X-Ray Diffraction Techniques

ASTM E2860 Test Method for Residual Stress Measurement by X-Ray Diffraction for Bearing Steels

2.1.3 European Standards Publications

Available from European Standards, K. Steinera 37, 31800 Plzen, Czech Republic, www.en-standard.eu.

EN 15305 Non-destructive testing - Test method for residual stress analysis by X-ray diffraction

2.1.4 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories

2.1.5 MMPDS Publications

Available from MMPDS, Tel: 614-424-6557, www.mmpds.org, bcommpps@battelle.org.

MMPDS Metallic Materials Properties Development and Standardization

2.1.6 ASM Publications

Available from ASM International, 9639 Kinsman Road, Materials Park, OH, 44073, Tel: 440-338-515, www.asminternational.org.

Totten, G., Howes, H., and Inoue, T. (2002). *Handbook of residual stress and deformation of steel*. ASM International.

2.1.7 SEM Publications

Available from the Society for Experimental Mechanics, 7 School Street, Bethel, CT 06801-1405, Tel: 203-790-6373, www.sem.org.

Lu, J. (Ed.). (1996). *Handbook of Measurement of Residual Stress*. Society for Experimental Mechanics, Fairmont Press.

2.1.8 Other Publications

Schajer, G.S. (Ed.). (2013). *Practical residual stress measurement methods*. John Wiley & Sons.

2.2 Definitions

Terms are defined in AS7766 and as follows:

2.2.1 BULK RESIDUAL STRESS

Also referred to as Category 1, residual stress, within this standard; bulk (interior) residual stress resulting from processes such as quench (differential cooling), heat treating, ageing, cold forming, cold working, or other processing of a product. Refer to Totten et al., 2002 (see 2.1.6) for additional examples. Process-induced residual stresses can still exist in parts machined from bulk residual stress bearing products. The location and magnitude of these stresses depends on the location and magnitude of the residual stress in the parent product, the position of the machined part within the parent product envelope, and other factors. Residual stress is a rank two tensor field quantity with six unique tensor components that vary through the volume of a product.

2.2.2 CHARACTERISTIC RESIDUAL STRESS

When attempting to demonstrate that a given residual stress is present within a body, including zero residual stress, it is neither practical nor necessary to apply an acceptance criterion at every material point in every orientation within the body. Furthermore, if measured data is being used in the evaluation, that data may only exist in limited, discrete form. As an example, some measurement techniques, like X-ray diffraction, produce a zero-dimensional (0D), or point, result. The terms "0D" and "point" are, of course, qualitative. In reality, the measured stress represents the average over the footprint of the incident X-ray beam. Multiple 0D measurements for a given footprint can be strung together to obtain 1D, 2D, or 3D stress fields. Some techniques produce a one-dimensional (1D) result, meaning that they characterize the continuous variation of residual stress along a line or path. An example of a 1D measurement is the slitting method, which produces a through-the-thickness average of residual stress along the slitting path. The contour method produces a two-dimensional (2D) result. This method characterizes the variation of residual stress over a cross-sectional plane of the body.

When this standard is used for the purpose of classification (see 1.3), it may be necessary to select or define a characteristic residual stress for comparison against the criteria in Table 1. The characteristic residual stress is a single value (or values), either taken directly from the measured or modeled data, or computed from that data. For example, when 1D data are used, the characteristic residual stress could be the maximum value of the residual stress along the measurement path, the average of the residual stress along the path (or portion of the path), or any combination or formula using the residual stress along the measurement path. When 2D or 3D data are used, the characteristic residual stress could be the maximum value of the residual stress on the measurement surface or within the measurement volume, the average of the residual stress over the measurement surface or within the measurement volume (or portion of the surface or volume), or some combination or formula using the residual stress over the surface or within the volume. For 1D, 2D, or 3D data, if the residual stress state is defined using the density of stored energy (W), which is the most representative indicator for machining distortion, then the classes defined in 1.3.2 shall not apply. The CEO shall prescribe the definition of characteristic residual stress for each application/zone. Generally speaking, the most appropriate characteristic residual stress definition will depend on the residual stress category and class (Table 1).

For Category 1 and Category 2, the intent is generally to limit the magnitude and/or upper limit of the residual stress, which are likely to occur in the interior of the material. In those cases, it is most appropriate to use a characteristic residual stress definition that will place an appropriate amount of assurance at this location. For example, with Category 1, a measurement technique might be selected with an application region that covers at least half of the material thickness and use the peak residual stress (or maybe the 90% value to limit the impact of potential outliers) as the characteristic residual stress. For Category 2, a multitude of points might be measured on across the weld and into the thickness and again use the peak residual stress value (or maybe the 90% value to limit the impact of potential outliers).

Category 3 is typically called out when residual stress generating processes (such as cold working or peening) have been applied to surfaces of the part and the CEO is concerned with: (1) ensuring that an appropriate amount of compression is present on/near the treated surface, and (2) ensuring that the compensating tensile stresses that develop are lower than the critical threshold. For example, for a shot peened part, the CEO may require demonstration that a given residual stress profile exists within the part. This could be accomplished by calling for one characteristic residual stress at or very near the surface, a second characteristic value at the expected zero-crossing depth, and a third at the expected maximum tension depth.

Category 4 is very open-ended and would likely require a characteristic residual stress definition that has a similar level of complexity.

2.2.3 CONTOUR METHOD

Residual stress measurement technique for measuring bulk residual stress within an entire cross-section of a part. The contour method involves cutting a part into two pieces, measuring the deformation on the cut surfaces, and performing an analysis to resolve a two-dimensional map of the residual stress normal to the measurement plane.

2.2.4 DEEP HOLE DRILLING

Residual stress measurement technique for measuring residual stress versus depth profile through the thickness of a part. The deep hole drilling method involves measuring the change in diameter of a reference hole caused by removing a core of surrounding material by trepanning. The profile of residual stress versus depth is found by performing an elastic analysis of the relaxation (change in reference hole diameter) caused by removal of the core.

2.2.5 ENGINEERED RESIDUAL STRESS

Also referred to as Category 3, residual stress, within this standard. Engineered (localized) residual stress are those imparted to a specified region of a finished product using a controlled engineering process, typically for the purpose of enhancing structural performance. Processes used for the installation of engineered residual stresses include conventional shot peening, laser shock peening, burnishing, localized cold working, and hole cold expansion. Engineered residual stress is a rank two tensor field quantity, with six unique tensor components that vary through the volume of a product.