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DEPARTMENT OF DEFENSE
HANDBOOK

INSPECTION OF WELDED JOINTS

This handbook is for guidance only. Do not cite this document as a requirement.

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FOREWORD

1. This handbook is approved for use by all Departments and Agencies of the Department of Defense.

2. This handbook is for guidance only. This handbook cannot be cited as a requirement. If it is, the contractor does not have to comply.

3. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: U.S. Army Tank-automotive and Armaments Command, ATTN: AMSTA-TR-E/BLUE, Warren, MI 48397-5000, by using the Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document, or by letter.

CONTENTS

1. SCOPE

1.1 Scope. This handbook gives guidance for nondestructive inspection of welded joints. This handbook is for guidance only. This handbook cannot be cited as a requirement. If it is, the contractor does not have to comply.

1.2 Purpose. This handbook covers the inspection of the five basic types of welded joints used in the manufacture of gas turbine tank engine components. The types of joints referenced are:

a. Butt
b. Corner
c. Edge
d. Lap
e. Tee

1.3 Welding processes. Processes categorized within groups that are incorporated in this handbook are as follows:

Group	Welding process	Letter designation
Arc welding (AW)	Gas tungsten arc (manual or automatic)	GTAW (MA or AU)
	Gas metal arc (manual or automatic)	GMAW (MA or AU)
	Shielded metal arc	SMAW
	Submerged arc	SAW
	Plasma arc	PAW
	Atomic hydrogen	AHW
Oxyfuel gas Welding(OFW)	Oxyacetylene welding	OAW
Resistance Welding (RW)	Resistance - seam welding	RSEW
	Resistance - spot welding	RSW

1.4 Classification. Weld joints should be classified as follows:

Class 1 - Joints subject to high stress or fatigue loading.
Class 2 - Joints subject to intermediate stresses or fatigue loading.
Class 3 - Joints subject to intermediate stresses.
Class 4 - Joints subject to low stresses.

2. APPLICABLE DOCUMENTS

2.1 General. The documents listed below are not necessarily all of the documents referenced herein, but are the ones that are needed in order to fully understand the information provided by this handbook.

2.2 Government documents.

2.2.1 Specifications, standards and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DoDISS).

SPECIFICATIONS

DEPARTMENT OF DEFENSE

MIL-W-6858 - Welding, Resistance: Spot and Seam.

STANDARDS

DEPARTMENT OF DEFENSE

MIL-STD-453 - Inspection, Radiographic.
MIL-STD-1264 - Radiographic Inspection For Soundness Of Welds In Steel By Comparison To Graded ASTM E390 Reference Radiographs.
MIL-STD-6866 - Inspection, Liquid Penetrant.

(Unless otherwise indicated, copies of the above specifications, standards, and handbooks are available from the Standardization Document Order Desk, 700 Robbins Avenue, Bldg. 4D, Philadelphia, PA 19111-5094.)

2.3 Non-Government publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise specified, the issues of the documents which are DOD adopted are those listed in the issue of the DODISS and supplement thereto.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM E390	- Standard Reference Radiographs for Steel Fusion Welds (DoD Adopted).
ASTM E1444	- Standard Practice for Magnetic Particle Examination.

(Application for copies should be addressed to the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959).

AMERICAN WELDING SOCIETY (AWS)

AWS A2.4	- Standard Symbols for Welding, Brazing and Nondestructive Examination.
AWS A3.0	- Welding Terms and Definitions Including Terms for Brazing Soldering Thermal Spraying and Thermal Cutting.

(Application for copies should be addressed to American Welding Society, 550 N.W. Lelune Road, Miami, FL 33126).

2.4 Order of precedence. In the event of a conflict between the text of this document and the 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.

3. DEFINITIONS

3.1 Definitions. Definitions of welding symbols and terms used herein shall conform to AWS A2.4 and AWS A3.0 respectively.

4. INSPECTIONS

4.1 General. This handbook covers the nondestructive inspection of welded joints.

4.2 Inspection sequence and methods. Inspection of welded joints should be done at a point where the entire joint is accessible for examination. It may be performed at the subassembly or assembly level.

4.2.1 Visual inspection. All welded joints should be visually examined to determine conformance to the acceptance criteria. Parts requiring heat treatment should be examined before and after performing this operation.

4.2.2 Fluorescent penetrant inspection. All welded joints in non-magnetic materials and materials welded with non-magnetic filler material should be fluorescent penetrant inspected in accordance with MIL-STD-6866 to determine conformance to the acceptance criteria. Should the parts require heat treatment, the inspection should be immediately after that operation.

4.2.3 Magnetic particle inspection. All welded joints in magnetic materials and materials welded with magnetic filler material, should be magnetic particle inspected in accordance with ASTM E1444 to determine conformance to the acceptance criteria. At completion of inspection the parts assemblies should be de-magnetized. Should the parts require heat treatment, the inspection should be immediately after that operation.

4.2.4 Radiographic and ultrasonic inspection. Unless otherwise specified on the engineering drawing, all welded joints should be radiographically or ultrasonically inspected. Radiographic inspection is detailed in MIL-STD-453. Ultrasonic inspection procedures are detailed in various industry standards based on the material being welded and the type of weld.

4.2.4.1 Frequency of inspection. Frequency of inspection should be based on weld joint classification as follows (see 1.4):

a. Class 1 weld joints. All Class 1 welded joints should be radiographically or ultrasonically inspected.
b. Class 2 weld joints. All class 2 weld joints should be radiographically or ultrasonically inspected until the quality level satisfactory to the acquisition agency has been established. At that point a sampling plan may be instituted by the acquisition activity.
c. Class 3 weld joints. All class 3 weld joints should be radiographically or ultrasonically inspected until the quality level satisfactory to the acquisition agency has been established. At that point a sampling plan may be instituted by the acquisition activity on the arc and oxyfuel gas welding processes.

d. Class 4 weld joint. Class 4 welded joints should not require radiographic or ultrasonic inspection.

4.3 Pressure test. When required, pressure tests should be performed in the proper sequence to determine conformance to the engineering requirements.

4.4 Acceptance criteria.

4.4.1 Arc (AW) and oxyfuel gas (OFW) welds. Welds resulting from fusion occurring in these processes should conform to the following:

a. Weld beads should be reasonably smooth and free from irregularities and should blend into the parent metal in smooth gradual curves.
b. The weld should show complete fusion without an excess of overlapping.
c. Edge weld penetration should be at least equal to or exceed thickness of the thinner material and should slightly overlap the outer edges of adjacent material to ensure the weld cross sectional area requirement.
d. The fillet weld size and intermittent or tack weld length should not be in excess of 1.5 times the value specified on the engineering drawing.
e. The surface imperfections of welds should be in accordance with the limits of acceptability stated in table I and II.
f. Scratches resulting from arc welding should not be evidenced on adjacent part areas.
g. Dimensional allowances for flush and convex welds should be as follows:

Nominal stock thickness inches(in.)	Flush weld allowance	Convex weld allowance
0.000 to 0.030	0% to +20%	+10% to +60%
0.031 to 0.080	0% to +15%	+10% to +50%
0.081 to 0.156	0% to +10%	+10% to +40%
0.157 and over	0% to +0.02 in. max.	+10% to 0.12 in. max.

h. Dimensional allowance for butt welds on the crown and under-bead is a maximum of one third the thickness of the thinner material.
i. Cracks, incomplete penetration or fusion, porosity and voids, and metallic and non-metallic inclusions should be in accordance with the limits stated in table III and IV. Comparison reference radiographs are available from ASTM E390 and MIL-STD-1264.

4.4.2 Resistance (RW) welds. Welds resulting from these processes should conform to the following:

a. The centerline of the material overlap should be the centerline of the spot or seam weld.
b. The spot and seam welds should be aligned within 0.060 in. of the centerline.
c. Seam welds should terminate within 0.120 in. of the ends of the weld run.
d. The surface imperfections of welds should be in accordance with the limits stated in table V.
e. There should be no evidence of arc or oxyfuel gas weld methods in association with resistance welding.
f. Cracks, porosity and voids, metal expulsion between sheets and surface flashes should be in accordance with the limits stated in table VI (see also MIL-W-6858).
g. When the nugget size is not specified in the engineering drawing, the minimum nugget size should be in accordance with MIL-W-6858.
h. A maximum of 5 gap areas between indentations circumferential weld joints should be permitted provided no individual gap exceeds 0.060 in. and the cumulative total of all gaps per joint does not exceed 0.250 in.

4.5 Rejection. Parts containing discontinuities or defects exceeding the permissible limits of the applicable specification, drawing, standard, or directive should be separated from the acceptable material, appropriately identified as discrepant, and submitted for review as may be provided in the contract. Weld rework which will restore weld areas to meet all engineering drawing requirements should only be done with concurrence of the acquisition. Care should be exercised to insure that the parent metal is not removed during the rework operations. All weld rework should be inspected in accordance with the applicable guidelines of 4.2.

4.6 Marking. Parts which conform satisfactorily to applicable inspection requirements should be marked in a manner and location harmless to the part that will preclude removal, smearing, or obliteration by subsequent handling. When processing which would remove identification is planned, the applicable symbol should be affixed to the records accompanying the parts. Impression stamping should be used where permitted. When applicable parts should be marked by etching, suitable etchants and application methods should be employed. Etching methods other than fluid etching may be used. Where etching or impression stamping is not appropriate, identification may be accomplished by dying. Other means of identification such as tagging may be applied to completely ground and polished parts for which construction, finish or functional requirement preclude the use of etching, stamping, or dyeing.

5. NOTES

5.1 Intended use. This handbook is intended to outline the methods for non-destructive inspection to insure that joints welded in accordance with the processes of this handbook will meet the inspection guidelines of section 4.2.

5.2 Post machining. Welded joints inspected in-process prior to machining of the weld, should require visual and fluorescent pentrant or magnetic particle inspection after machining operations.

5.3 Physical limitations. When part configuration or size make magnetic particle inspection impractical, the weld joint may be inspected by fluorescent penetrant method providing approval has been given in writing by the responsible acquisition agency.

5.4 Straightening. Parts distorted as a result of excessive overall or localized heat input during welding, may be straightened provided they are not in the heat treated condition. Parts should be fluorescent penetrant or magnetic particle inspected for cracks after the straightening operation.

5.5 Subject term (key word) listing.

Arc
Engine
Fluorescent
Magnetic
Nondestructive
Particle
Penetrant
Radiographic
Resistance
Testing
Turbine
Ultrasonic
Visual
Welding

TABLE I. Visual, fluorescent penetrant and magnetic particle inspection acceptance limits for arc or oxyfuel gas welded joints (iron, nickel and cobalt base alloys)

Type of defect	Class 1	Class 2	Class 3	Class 4
Cracks and crack-like indications	U	U	U	U
Incomplete penetration & fusion	U	U	U	U
Surface porosity				
Max. size “D”	U	T/4 up to 0.060 max.	T/3 up to 0.060 max.	T/3 up to 0.100 max.
Max total	U	2 of max. size or equivalent length	3 of max. size	5 of max. size or equivalent length
Min. distance between indications	U	4D	3D	2D
Undercutting				
Max. depth	U	T/20	T/15	T/ 10
Max. length	U	10T IN 50T	10T IN 20T	10T IN 20T

U - Unacceptable.
T - Thickness of thinnest base material.
D - Diameter of largest dimension of defect(s).

TABLE II. Visual and fluorescent penetrant and inspection acceptance limits for arc or oxyfuel gas welded joints (aluminum, magnesium, copper and titanium base alloys)

Type of defect	Class 1	Class 2	Class 3	Class 4
Cracks and crack-like indications	U	U	U	U
Incomplete penetration & fusion	U	U	U	U
Surface porosity				
Max. size "D"	U	T/3 up to 0.060 max.	T/2 up to 0.080 max.	T/2 up to 0.100 max.
Max total length per linear inch	U	4 of max. size or equivalent length	5 of max. size or equivalent length	5 of max. size or equivalent length
Min. distance between indications	U	3D	2D	1D
Undercutting				
Max. depth	U	T/20	T/15	T/ 10
Max. length	U	10T IN 20T	10T IN 20T	10T IN 20T

U - Unacceptable.
T - Thickness of thinnest base material.
D - Diameter of largest dimension of defect(s).

TABLE III. Radiographic and ultrasonic inspection acceptance limits for arc or oxyfuel gas welded joints (iron, nickel and cobalt base alloys)

Type of defect	Class 1	Class 2	Class 3
Cracks (weld and base material), including cavities or inclusions with a tail	U	U	U
Incomplete penetration & fusion	U	Butt and corner welds: U. Fillet welds: max length - 4T in any 10T length of weld, or 40% of joint length, whichever is less. Plug: 20% along crcmf.	Butt and corner welds: U. Fillet welds: max length - 10T in any 20T length of weld, or 50% of joint length, whichever is less. Plug: 50% along crcmf.
Porosity & voids Max. size "D" Max total length per linear inch Min. distance between indications	 T/3 up to 0.060 max. 2 of max. size or equivalent length 5D	 T/2 up to 0.080 max. 3 of max. size or equivalent length 4D	 T/2 up to 0.100 max. 6 of max. size or equivalent length 3D
Metallic and non-metallic inclusions Max. size "D" Max. total length Min. distance between indications	 T/3 up to 0.060 max. 2 of max. size or equivalent length 5D	 T/2 up to 0.080 max. 3 of max. size or equivalent length 4D	 T/2 up to 0.100 max. 4 of max. size or equivalent length 3D

U - Unacceptable.
T - Thickness of thinnest base material.
D - Diameter of largest dimension of defect(s).

Table IV. Radiographic and ultrasonic inspection acceptance limits for arc or oxyfuel gas welded joints (aluminum, magnesium, copper titanium base alloys)

Type of defect	Class 1	Class 2	Class 3
Cracks (weld and base material), including cavities or inclusions with a tail	U	U	U
Incomplete penetration & fusion	U	Butt and corner welds: U. Fillet welds: max length - 4T in any 10T length of weld, or 40% of joint length, whichever is less.	Butt and corner welds: U. Fillet welds: max length - 10T in any 20T length of weld, or 50% of joint length, whichever is less.
Coarse porosity & voids Max. size "D" Max total length per linear inch Min. distance between indications	T/2 up to 0.060 max. 3 of max. size or equivalent length 4D	T/2 up to 0.100 max. 6 of max. size or equivalent length 2D	T/2 up to 0.100 max. 10 of max. size or equivalent length 1D
Fine porosity Max. size "D" Max. total length per linear inch Min. distance between indications	T/5 up to 0.015 20 of max. size or equivalent length 2D	T/5 up to 0.015 no limit 1D	T/5 up to 0.025 no limit 1D
Metallic and non-metallic inclusions Max. size "D" Max. total length per linear inch Min. distance between indications	T/3 up to 0.060 max. 2 of max. size or equivalent length 5D	T/2 up to 0.080 max. 3 of max. size or equivalent length 4D	T/2 up to 0.100 max. 4 of max. size or equivalent length 3D

U - Unacceptable.
T - Thickness of thinnest base material.
D - Diameter of largest dimension of defect(s).

TABLE V. Visual, fluorescent penetrant and magnetic particle inspection acceptance limits for resistance welded joints (all alloys).

Type of defect	Class 1		Class 2		Class 3	
	Spot	Seam	Spot	Seam	Spot	Seam
Cracks or crack-like indications	U	U	U	U	U	U
Surface pits (or clusters) Max. size "D"	0.04	0.04	0.06	0.06	0.06	0.06
Max. number	10% of N	3 per linear inch or equivalent length	20% of N	5 per linear inch or equivalent length	30% of N	5 per linear inch or equivalent length
Electrode Pickup Max. acceptable	2% of N	2% of joint length and/or W per linear inch	3% of N	3% of joint length and/or W per linear inch	5% of N	5% of joint length and/or W per linear inch
Sheet Separation Max. acceptable length	3% of N	3% of joint length and/or 3W max length	10% of N	10% of joint length and/or 5W max length	20% of N	20% of joint length and/or 5W max length
Max. acceptable separation	0.005 or T/10 whichever is greater	0.005 or T/10 whichever is greater	0.005 or T/10 whichever is greater	0.005 or T/10 whichever is greater	0.005 or T/10 whichever is greater	0.005 or T/10 whichever is greater
Excessive Indentation Max. acceptance	3% of N	3% of joint length and/or W per linear inch	10% of N	10% of joint length and/or W per linear inch	20% of N	20% of joint length and/or W per linear inch

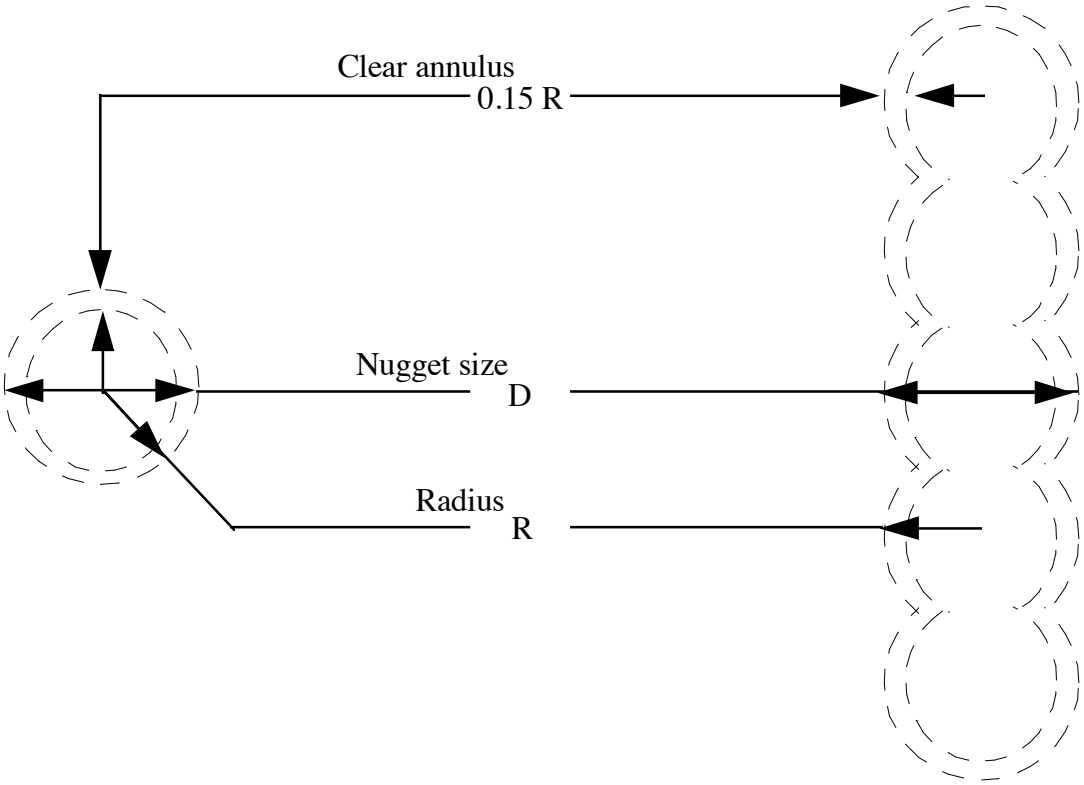
U - Unacceptable.
D - Diameter of largest dimension of defect.
W - Weld nugget diameter.
N - Number of spotwelds in the joint.
T - Thickness of thinnest sheet.

TABLE VI. Radiographic and ultrasonic inspection acceptance limits for resistance welded joints (all alloys, except as noted [1]).

Type of defect	Class 1		Class 2		Class 3	
	Spot	Seam	Spot	Seam	Spot	Seam
Cracks	U	U	U	U	U	U
Fine porosity:						
Max. size "D"	0.01	0.01	0.015	0.015	0.025	0.025
Max. number of indications	2 indications per spot in 30% of N	5 per linear inch	2 indications per spot in 50% of N	10 per linear inch	2 indications per spot in 50% of N	15 per linear inch
Min. distance between indications	2D	2D	1D	1D	1D	1D
Void and large porosity:						
Max. size	W/4	W/4	W/2	W/2	W/2	W/2
Max. number of indications	in 25% of N, 2 successive spots	3 of max. size per linear inch or equivalent length	in 35% of N, 4 successive spots	3 of max. size per linear inch or equivalent length	in 50% of N, 6 successive spots	5 of max. size per linear inch or equivalent length
Limits of extension within the nugget	to within 15% of W of fusion line	to within 15% of W of fusion line	to within 10% of W of fusion line	to within 10% of W of fusion line	to within 5% of W of fusion line	to within 5% of W of fusion line
Min. distance between indications	1D	1D	1D	1D	1D	1D
Metal expulsion between sheets (spits) and surface flashes - max. acceptable						
Nickel and cobalt based alloys	30% of N	6 per linear inch	50% of N	10 per linear inch	60% of N	15 per linear inch
All other alloys	10% of N	3 per linear inch	25% of N	5 per linear inch	35% of N	10 per linear inch

U - Unacceptable.
D - Diameter of largest dimension of defect.
W - Weld nugget diameter.
N - Number of spotwelds in the joint.
T - Thickness of thinnest sheet.

Notes: (1) See Figure 1. (reference MIL-W-6858)



Note:

1. No part should be acceptable when the number of welds having cracks, pores, or other instances of incomplete fusion with a linear dimension greater than 0.15D or that extend into the 0.15R clear annulus area, extends 6 percent of the total number of welds in the part.

FIGURE 1. Radiographic criteria for spot and seam welds in aluminum and aluminum alloys.

CONCLUDING MATERIAL

Custodians:
Army - AT

Preparing activity:
Army - AT

(Project NDTI-0249)