



American
Gear Manufacturers
Association

Technical Resources

ANSI/AGMA 1010-F14
(Revision of ANSI/AGMA 1010-E95)
Reaffirmed February 6, 2020

American National Standard

Appearance of Gear Teeth - Terminology of Wear and Failure

**American
National
Standard**

Appearance of Gear Teeth - Terminology of Wear and Failure

ANSI/AGMA 1010-F14

[Revision of ANSI/AGMA 1010-E95]

Approval of an American National Standard requires verification by ANSI that the requirements for due process, consensus and other criteria for approval have been met by the standards developer.

Consensus is established when, in the judgment of the ANSI Board of Standards Review, substantial agreement has been reached by directly and materially affected interests. Substantial agreement means much more than a simple majority, but not necessarily unanimity. Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution.

The use of American National Standards is completely voluntary; their existence does not in any respect preclude anyone, whether he has approved the standards or not, from manufacturing, marketing, purchasing or using products, processes or procedures not conforming to the standards.

The American National Standards Institute does not develop standards and will in no circumstances give an interpretation of any American National Standard. Moreover, no person shall have the right or authority to issue an interpretation of an American National Standard in the name of the American National Standards Institute. Requests for interpretation of this standard should be addressed to the American Gear Manufacturers Association.

CAUTION NOTICE: AGMA technical publications are subject to constant improvement, revision or withdrawal as dictated by experience. Any person who refers to any AGMA Technical Publication should be sure that the publication is the latest available from the Association on the subject matter.

[Tables or other self-supporting sections may be referenced. Citations should read: See ANSI/AGMA 1010-F14, *Appearance of Gear Teeth - Terminology of Wear and Failure*, published by the American Gear Manufacturers Association, 1001 N. Fairfax Street, Suite 500, Alexandria, Virginia 22314, <http://www.agma.org>.]

Approved August 8, 2014

ABSTRACT

This nomenclature standard identifies and describes the classes of common gear failures and illustrates degrees of deterioration.

Published by

**American Gear Manufacturers Association
1001 N. Fairfax Street, Suite 500, Alexandria, Virginia 22314**

Copyright © 2014 by American Gear Manufacturers Association
All rights reserved.

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without prior written permission of the publisher.

Printed in the United States of America

ISBN: 978-1-61481-089-6

Contents

Foreword	vii
1 Scope	1
2 Normative references	1
3 Definitions	1
3.1 Definitions	1
3.2 Classes and modes of failure	2
4 Wear	3
4.1 Adhesion	3
4.1.1 Mild adhesion	4
4.1.2 Moderate adhesion	4
4.1.3 Summary of methods to reduce the risk of adhesive wear	5
4.2 Abrasion	5
4.2.1 Mild abrasion	5
4.2.2 Moderate abrasion	6
4.2.3 Severe abrasion	6
4.2.4 Sources of particles that may cause wear	8
4.2.5 Methods for reducing abrasive wear	8
4.3 Polishing	9
4.3.1 Mild polishing	9
4.3.2 Moderate polishing	9
4.3.3 Severe polishing	9
4.3.4 Summary of methods to reduce the risk of polishing wear	10
4.4 Corrosion	10
4.4.1 Methods to reduce the risk of corrosion	11
4.5 Fretting	12
4.5.1 True brinelling	12
4.5.2 False brinelling	13
4.5.3 Fretting corrosion	13
4.5.4 Summary of methods to reduce the risk of false brinelling and fretting corrosion	13
4.6 Scaling	14
4.7 White layer flaking	14
4.7.1 Summary of methods to reduce the risk of white layer flaking	15
4.8 Cavitation	15
4.9 Erosion	17
4.10 Electric discharge	18
4.10.1 Summary of methods to reduce the risk of electrical discharge damage	21
5 Scuffing	21
5.1 Mild scuffing	21
5.2 Moderate scuffing	21
5.3 Severe scuffing	23
5.3.1 Methods for reducing the risk of scuffing	25
5.3.2 Summary of methods to reduce the risk of scuffing	26
6 Plastic deformation	26
6.1 Indentation	26
6.2 Cold flow	27
6.3 Hot flow	27
6.4 Rolling	27

6.5	Tooth hammer	27
6.6	Rippling	27
6.7	Ridging	30
6.8	Burr.....	30
6.9	Root fillet yielding	31
6.10	Tip-to-root interference.....	31
6.11	Tight mesh.....	31
7	Hertzian fatigue.....	32
7.1	Macropitting.....	32
7.1.1	Nonprogressive macropitting	32
7.1.2	Progressive macropitting.....	34
7.1.3	Point-surface-origin macropitting	34
7.1.4	Spall macropitting.....	37
7.2	Micropitting.....	39
7.2.1	Summary of methods to reduce the risk of micropitting.....	43
7.3	Subsurface initiated failures	44
7.3.1	Inclusion origin failures.....	44
7.3.2	Origins of nonmetallic inclusions.....	44
7.4	Subcase fatigue.....	45
7.4.1	Summary of methods to reduce the risk of subcase fatigue.....	46
8	Cracking and other surface damage.....	46
8.1	Hardening cracks	46
8.1.1	Thermal stresses.....	47
8.1.2	Stress concentration	47
8.1.3	Quench severity	47
8.1.4	Phase transformation	48
8.1.5	Steel grades	48
8.1.6	Part defects	48
8.1.7	Heat treating practice	48
8.1.8	Tempering practice	48
8.1.9	Summary of methods to reduce the risk of hardening cracks.....	48
8.2	Grinding damage.....	49
8.2.1	Grinding cracks	49
8.2.2	Overheating due to grinding.....	49
8.2.3	Summary of methods to reduce the risk of grinding cracks.....	50
8.3	Rim and web cracks.....	50
8.3.1	Summary of methods to reduce the risk of rim or web cracks.....	50
8.4	Case/core separation	52
8.4.1	Summary of methods to reduce the risk of case/core separation.....	54
8.5	Fatigue cracks	54
9	Fracture.....	55
9.1	Brittle fracture	55
9.1.1	Methods for reducing the risk of brittle fracture.....	58
9.2	Ductile fracture	58
9.3	Mixed mode fracture	59
9.4	Tooth shear	59
9.5	Fracture after plastic deformation	59

10	Bending fatigue	61
10.1	Low cycle fatigue.....	62
10.2	High cycle fatigue.....	62
10.2.1	Morphology of fatigue fracture surfaces.....	63
10.2.2	Summary of methods to reduce the risk of high-cycle bending fatigue	64
10.2.3	Root fillet cracks.....	65
10.2.4	Profile cracks.....	65
10.2.5	Tooth end cracks.....	66
10.2.6	Subsurface initiated bending fatigue cracks	66
10.2.7	Tooth interior fatigue fracture, TIFF	73

Annexes

Annex A	Design considerations to reduce the chance of failure	75
Annex B	Bibliography.....	79
Annex C	Acknowledgements	81

Tables

Table 1	- Nomenclature of gear failure modes.....	2
Table 2	- Failure modes that have subsurface origins.....	44
Table 3	- Fracture classifications	55
Table 4	- Differences between TIFF and subsurface initiated bending fatigue	74

Figures

Figure 1	- Moderate wear.....	3
Figure 2	- Severe wear.....	4
Figure 3	- SEM image - abrasion	6
Figure 4	- Mild abrasion near the tip of a ground gear.....	6
Figure 5	- Severe abrasion.....	7
Figure 6	- Severe abrasion, enlarged view of Figure 5.....	7
Figure 7	- Severe abrasion.....	7
Figure 8	- Severe polishing	10
Figure 9	- Severe polishing	10
Figure 10	- Extensive corrosion	11
Figure 11	- Fretting corrosion.....	12
Figure 12	- Scaling	14
Figure 13	- White layer flaking	15
Figure 14	- Cavitation damage.....	16
Figure 15	- Cavitation damage.....	16
Figure 16	- SEM image - cavitation damage.....	17
Figure 17	- SEM image - cavitation damage.....	17
Figure 18	- Erosion of a high speed helical gear	18
Figure 19	- Electric discharge damage due to a small electric current.....	19
Figure 20	- Severe electric discharge damage due to an electric current of high intensity	19
Figure 21	- SEM image - typical electric discharge crater	20
Figure 22	- SEM image - remelted metal and gas pockets near edge of crater	20
Figure 23	- SEM image - electric discharge damage.....	21
Figure 24	- Mild scuffing.....	22
Figure 25	- SEM image - scuffing damage showing rough, torn, and plastically deformed appearance ..	22
Figure 26	- SEM image - scuffing damage showing crater formed when welded material was torn from surface	23
Figure 27	- Moderate scuffing	23
Figure 28	- Severe scuffing.....	24
Figure 29	- Severe scuffing of a low speed gear lubricated with grease	24
Figure 30	- Severe indentations.....	27
Figure 31	- Hot flow.....	28
Figure 32	- Plastic deformation by rolling.....	28
Figure 33	- Plastic deformation by tooth hammer	29
Figure 34	- Rippling.....	29

Figure 35 - Rippling.....	29
Figure 36 - Rippling.....	30
Figure 37 - Ridging.....	30
Figure 38 - Burr.....	31
Figure 39 - Tip-to-root interference.....	32
Figure 40 - Cross section through a tooth flank showing how a pit develops below the surface.....	32
Figure 41 - SEM image - pitting damage caused by Hertzian fatigue, showing fatigue cracks near boundary of pit.....	33
Figure 42 - Nonprogressive macropitting.....	33
Figure 43 - Progressive macropitting.....	34
Figure 44 - Point-surface-origin macropitting.....	34
Figure 45 - Point-surface-origin macropitting.....	35
Figure 46 - Point-surface-origin macropitting.....	35
Figure 47 - Point-surface-origin macropitting on carburized helical gear at 1.5×10^7 cycles.....	36
Figure 48 - Point-surface-origin macropitting on carburized helical gear at 3.0×10^7 cycles.....	36
Figure 49 - Point-surface-origin macropitting on carburized helical driven pinion.....	37
Figure 50 - Point-surface-origin macropitting.....	37
Figure 51 - Spall macropitting.....	38
Figure 52 - Micropitting on misaligned carburized gear.....	39
Figure 53 - Micropitting on induction hardened spur gear with crowned teeth.....	39
Figure 54 - Micropitting on nitrided and ground spur gear.....	40
Figure 55 - Detail of tooth surface showing micropitting.....	40
Figure 56 - Detail of tooth surface showing micropitting at 1000X magnification.....	41
Figure 57 - Regularly distributed micropitting.....	41
Figure 58 - Subcase fatigue.....	45
Figure 59 - Crack at a forging defect.....	46
Figure 60 - Hardening cracks.....	47
Figure 61 - Grinding cracks with a crazed pattern.....	49
Figure 62 - Rim crack.....	51
Figure 63 - Rim cracks in through hardened annulus gear.....	51
Figure 64 - Fracture surface of rim crack shown in Figure 63.....	52
Figure 65 - Case/core separation.....	52
Figure 66 - Case/core separation.....	53
Figure 67 - Bending fatigue crack.....	54
Figure 68 - Brittle fracture.....	56
Figure 69 - SEM image of transgranular brittle fracture.....	56
Figure 70 - SEM image of intergranular brittle fracture.....	57
Figure 71 - SEM image of ductile fracture.....	59
Figure 72 - Mixed mode fracture.....	60
Figure 73 - Tooth shear.....	60
Figure 74 - Fracture after plastic deformation.....	61
Figure 75 - Two adjacent teeth on a helical pinion that failed by bending fatigue.....	63
Figure 76 - Bending fatigue of spiral bevel tooth.....	64
Figure 77 - Bending fatigue of two helical teeth.....	65
Figure 78 - Bending fatigue of several spur gear teeth.....	66
Figure 79 - Bending fatigue of two bevel pinion teeth.....	67
Figure 80 - Fatigue of several teeth that were loaded on both flanks.....	68
Figure 81 - Profile cracks originating from severe pitting.....	69
Figure 82 - Broken tooth ends.....	69
Figure 83 - Bending fatigue initiation from subsurface nonmetallic inclusion.....	70
Figure 84 - Bending fatigue due to nonmetallic inclusion.....	70
Figure 85 - Fracture surface of loose fragment showing nonmetallic inclusion.....	71
Figure 86 - BSE image of fracture surface showing scanned areas 1, 2, and 3.....	71
Figure 87 - EDS spectrum of figure 86 area 1 showing chemistry of the inclusion.....	72
Figure 88 - EDS spectrum of figure 86 area 3 showing chemistry of the steel matrix.....	72
Figure 89 - TIFF failure on an idler gear.....	73

Foreword

[The foreword, footnotes and annexes, if any, in this document are provided for informational purposes only and are not to be construed as a part of ANSI/AGMA 1010-F14, *Appearance of Gear Teeth - Terminology of Wear and Failure.*]

This standard provides a means to describe the appearance of gear teeth when they wear or fail. The study of gear tooth wear and failure has been hampered by the inability of two observers to describe the same phenomenon in terms that are adequate to assure uniform interpretation.

The term "gear failure" is subjective and a source of considerable disagreement. For example, a person observing gear teeth that have a bright, mirrorlike appearance may believe that the gears have "run-in" properly. However, another observer may believe that the gears have failed by polishing wear. Whether the gears should be considered failed or not depends on how much change from original condition is tolerable.

This standard provides a common language to describe gear wear and failure, and serves as a guide to uniformity and consistency in the use of that language. It describes the appearance of gear tooth failure modes and discusses their mechanisms, with the sole intent of facilitating identification of gear wear and failure. The purpose of the standard is to improve communication between equipment users and gear manufacturers for failure and wear analysis. Since there may be many different causes for each type of gear tooth wear or failure, it is not possible in the standard to identify a single cause for each type of wear or failure, nor to prescribe remedies.

AGMA Standard 110 was first published in 1943. A revised standard, AGMA 110.03, was published in 1979 with improved photographs and additional material. AGMA 110.04 was reaffirmed by the members in 1989.

ANSI/AGMA 1010-E95 was a revision of AGMA 110.04. It was approved by the AGMA Membership in March 9, 1995. It was approved as an American National Standard on December 13, 1995.

ANSI/AGMA 1010-F14 is a revision of ANSI/AGMA 1010-E95. It merges ANSI/AGMA 1010-E95 and AGMA 912-A04. New failure modes and additional photos were added and the content was reorganized. The description of failure mode morphology and mechanism was expanded, and methods to reduce the risk of a particular failure mode were added to the description of many of the failure modes.

The first draft of ANSI/AGMA 1010-F14 was made in August, 2010. It was approved by the AGMA membership in June, 2014. It was approved as an American National Standard on August 8, 2014.

Suggestions for improvement of this standard will be welcome. They may be submitted to tech@agma.org.

PERSONNEL of the AGMA Nomenclature Committee

Chairman: Dwight Smith Cole Manufacturing Systems
Vice Chairman: J.M. Rinaldo..... Atlas Copco Comptec, LLC

ACTIVE MEMBERS

J.B. Amendola, III Artec Machine Systems
K. Burris..... Caterpillar, Inc.
R.L. Errichello..... Geartech
O.A. LaBath..... Gear Consulting Services of Cincinnati, LLC
M. Li..... Lufkin Industries, Inc.
P. Terry..... P. Terry & Associates

American National Standard -

Appearance of Gear Teeth - Terminology of Wear and Failure

1 Scope

This standard provides nomenclature for general modes of gear tooth wear and failure. It classifies, identifies, and describes the most common types of failure and provides information that will, in many cases, enable the user to identify failure modes and evaluate the degree or change from original condition.

This standard is based on experience with steel gears; however, many of the failure modes discussed may apply to gears made from other materials.

The solution to many gear problems requires detailed investigation and analysis by specialists and is beyond the scope and intent of this standard.

This standard does not define "gear failure". One observer's "failure" is another observer's "run-in". There is no single definition of gear failure, since whether or not a gear has failed depends on the specific application.

The methods given for reducing the risk of a failure mode are specific to the failure mode considered, and implementation may sometimes worsen, or create other failure modes or unintended consequences. Therefore, it is imperative that any remedy be evaluated prior to implementation and thoroughly tested and evaluated after implementation.

NOTE: "gear" throughout the standard means gear or pinion unless the gear is specifically identified.

2 Normative references

The following documents contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions were valid. All publications are subject to revision, and the users of this standard are encouraged to investigate the possibility of applying the most recent editions of the publications listed:

AGMA 901-A92, *A Rational Procedure for the Preliminary Design of Minimum Volume Gears*

AGMA 923-B05, *Metallurgical Specifications for Steel Gearing*

ANSI/AGMA 1012-G05, *Gear Nomenclature, Definitions of Terms with Symbols*

ANSI/AGMA/AWEA 6006-A03, *Standard for Design and Specification of Gearboxes for Wind Turbines*

ANSI/AGMA 6011-I03, *Specification for High Speed Helical Gear Units*

ANSI/AGMA 6013-A06, *Standard for Industrial Enclosed Gear Drives*

ANSI/AGMA 9005-E02, *Industrial Gear Lubrication*

ISO 14104, *Gears - Surface temper etch inspection after grinding*

3 Definitions

3.1 Definitions

The terms used in this standard, wherever applicable, conform to the definitions given in ANSI/AGMA 1012-G05 and AGMA 923-B05.

NOTE: The symbols and definitions used in this standard may differ from other AGMA Standards. The user should not assume that familiar symbols can be used without a careful study of these definitions.