INTERNATIONAL STANDARD

ISO 6691

Second edition
2000-05-15

Thermoplastic polymers for plain bearings — Classification and designation

Polymères thermoplastiques pour paliers lisses — Classification et désignation

Reference number
ISO 6691:2000(E)

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Printed in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 6691 was prepared by Technical Committee ISO/TC 123, *Plain bearings*, Subcommittee SC 2, *Materials and lubricants, their properties, characteristics, test methods and testing conditions*.

This second edition cancels and replaces the first edition (ISO 6691:1989), of which has been technically revised.

Annexes A and B of this International Standard are for information only.

Thermoplastic polymers for plain bearings — Classification and designation

1 Scope

This International Standard specifies a classification and designation system for a selection of the most common unfilled thermoplastic polymers for plain bearings.

The unfilled thermoplastic polymers are classified on the basis of appropriate levels of distinctive properties, additives and information about their application for plain bearings. The designation system does not include all properties; thermoplastic polymers having the same designation cannot therefore be interchanged in all cases.

It also provides an outline of the properties and applications of the most common unfilled thermoplastic polymers as well as listing some of the fundamental parameters that influence the selection of thermoplastic polymers for use for plain bearings.

NOTE In the further course of the work it is intended to prepare standards on "thermosetting polymers" and "mixed polymers" for plain bearings.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 307, *Plastics — Polyamides — Determination of viscosity number*.

ISO 527-1, *Plastics — Determination of tensile properties — Part 1: General principles.*

ISO 527-2, *Plastics — Determination of tensile properties — Part 2: Test conditions for moulding and extrusion plastics.*

ISO 527-3, *Plastics — Determination of tensile properties — Part 3: Test conditions for films and sheets.*

ISO 527-4, *Plastics — Determination of tensile properties — Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites.*

ISO 527-5, *Plastics — Determination of tensile properties — Part 5: Test conditions for unidirectional fibre-reinforced plastic composites.*

ISO 1133, *Plastics — Determination of the melt mass-flow rate (MFR) and the melt volume-flow rate (MVR) of thermoplastics.*

ISO 1183, *Plastics — Methods for determining the density and relative density of non-cellular plastics.*

ISO 1628-5, *Plastics — Determination of the viscosity of polymers in dilute solution using capillary viscometers — Part 5: Thermoplastic polyester (TP) homopolymers and copolymers*.

ISO 1872-2, *Plastics — Polyethylene (PE) moulding and extrusion materials — Part 2: Preparation of test specimens and determination of properties*.

ISO 1874-2, *Plastics — Polyamide (PA) moulding and extrusion materials — Part 2: Preparation of test specimens and determination of properties*.

ISO 7148-2, *Plain bearings — Testing of the tribological behaviour of bearing materials — Part 2: Testing of polymer-based bearing materials*.

3 Classification and designation system

3.1 General

The classification and designation are based on a block system consisting of a "description block" and "identity block". The "identity block" comprises an "International Standard number block" and an "individual item block". For unambiguous coding of all thermoplastic polymers, the "individual item block" is subdivided into five data blocks.

Designation						
Description block	Identity block					
	International Standard number block	Individual item block				
		Data block 1	Data block 2	Data block 3	Data block 4	Data block 5

The "individual item block" starts with a dash. The data blocks are separated by commas.

Data blocks 1 to 5 include the following information:

data block 1: material symbol (see 3.2)

data block 2: intended application or method of processing (see 3.3)

data block 3: distinctive properties (see 3.4)

data block 4: type and content of fillers or reinforcing materials (see 3.5)

data block 5: information about tribological properties for plain bearings (see 3.6)

The meaning of the letters and digits is different for each data block (see 3.2 to 3.6).

Data block 2 comprises up to 4 positions. If at least one of positions 2 to 4 is used, but no information is given in position 1, then the letter "X" shall be placed in position 1. The letters in positions 2 to 4 shall be arranged in alphabetical order.

If a data block is not used, this shall be indicated by consecutive data block separators, i.e. two commas (,,).

Designation examples are given in clause 4.

3.2 Data block 1

The chemical nature of the thermoplastic polymer is designated by its symbol in accordance with ISO 1043-1.

Table 1 — Symbols for the chemical structure of the materials

Thermoplastic polymers		**Name and chemical structure**
Group/Name	Symbol	
Polyamide	PA 6	Polyamide 6; homopolymer based on ε-caprolactam
	PA 6 cast	Polyamide 6, cast; homopolymer based on ε-caprolactam
	PA 66	Polyamide 66; homopolycondensate based on hexamethylenediamine and adipic acid
	PA 12	Polyamide 12; homopolymer based on ω-laurinlactam or ω-aminododecanoic acid
	PA 12 cast	Polyamide 12, cast; homopolymer based on ω-laurinlactam or ω-aminododecanoic acid
	PA 46	Polyamide 46; a co-condensate based on 1,4-diaminabutane and adipic acid
Polyoxymethylene	POM	Polyacetal (homopolymer) Polyacetal (copolymer)
Polyalkyleneterephthalate	PET	Polyethylene terephthalate
	PBT	Polybutylene terephthalate
Polyethylene	PE-UHMW	Polyethylene with ultra high molecular weight
	PE-HD	High density polyethylene
Polyfluorocarbon	PTFE	Polytetrafluoroethylene
Polyimide	PI	Polyimides from polyaddition reactions are available as thermo-setting plastics. Polyimides from polycondensation reactions are available as thermoplastics and thermosetting plastics, as well as copolymers of the imide group. Some thermoplastic polyimides are "apparent thermosetting plastics" because their thermoplastic range lies above the decomposition temperature. Because of their intermediate position, polyimides and imide copolymers are only treated marginally in this International Standard.
Polyetheretherketone	PEEK	Polyaryletherketone
Polyvinylidene fluoride	PVDF	Homopolymer based on difluorodichloroethane
Polyphenylene sulfide	PPS	Polyphenylene sulfide, linearly structured phenyl ring and sulfur atoms (tribologically modified material)
Poly(amide-imide)	PAI	Poly(amide-imide) reacted by polycondensation is a hard/tough, amorphous thermoplastic. After postcuring the PAI parts cannot be used for re-processing ("pseudo-thermoset plastics").

3.3 Data block 2

Position 1 gives the code for the intended application (see Table 2).

Table 2 — Data block 2 — Position 1

Code	Intended application
E	Extrusion
G	General use
M	Injection moulding
Q	Compression moulding
R	Rotational moulding
X	No indication

Up to three important properties and/or additives can be indicated in positions 2 to 4 (see Table 3).

Table 3 — Data block 2 — Positions 2 to 4

Code	Intended application
A	Processing stabilized
F	Special burning characteristics
H	Heat ageing stabilized
L	Light and weather stabilized
R	Release agent
S	Slip agent, lubricated

3.4 Data block 3

3.4.1 General

The levels of distinctive properties are coded by letters and numbers.

The properties used for the designation are different for every thermoplastic polymer.

Owing to manufacturing tolerances, single property values can lie on, or to either side of, two intervals. It is up to the manufacturer to state which interval will designate the thermoplastic polymer.

3.4.2 Polyamides

Polyamides are designated in data block 3 by their viscosity number, represented by two digits (see Table 4) in accordance with ISO 1874-1 and, separated by a dash, their modulus of elasticity represented by three digits (see Table 5).

In the last position, rapid-setting products may be indicated with the letter N.

The viscosity number shall be determined in accordance with ISO 307 using the solvents given in Table 4. The modulus of elasticity shall be determined in the dry state in accordance with ISO 527-1, ISO 527-2, ISO 527-3, ISO 527-4 and ISO 527-5, under the conditions specified in ISO 1874-2.

Table 4 — Viscosity number for polyamides

Polyamide	Code	**Viscosity number**, ml/g			
		Solvent			
		Sulfuric acid 96 % (*m*/*m*)		*m*-cresol	
		>	⩽	>	⩽
PA 6 PA 6 cast PA 66	**09**	—	90		
	10	90	110		
	12	110	130		
	14	130	160		
	18	160	200	—	
	22	200	240		
	27	240	290		
	32	290	340		
	34	340	—		
PA 12 PA 12 cast	**11**			—	110
	12			110	130
	14			130	150
	16	—		150	170
	18			170	200
	22			200	240
	24			240	—

Table 5 — Modulus of elasticity

Code	**Modulus of elasticity** N/mm^2	
	>	⩽
001	50	150
002	150	250
003	250	350
004	350	450
005	450	600
007	600	800
010	800	1 500
020	1 500	2 500
030	2 500	3 500
040	3 500	4 500
050	4 500	5 500
060	5 500	6 500
070	6 500	7 500
080	7 500	8 500
090	8 500	9 500
100	9 500	10 500
110	10 500	11 500
120	11 500	13 000
140	13 000	15 000
160	15 000	17 000
190	17 000	20 000
220	20 000	23 000
250	23 000	—

3.4.3 Polyethylenes

Polyethylenes are designated by their density represented by two digits (see Table 6) in accordance with ISO 1872-1 and, separated by a dash, their melt flow rate (MFR) represented by one letter and three digits (see Table 7).

The density of the base material shall be determined in accordance with ISO 1183 under the conditions specified in ISO 1872-2.

The melt flow rate shall be determined in accordance with ISO 1133 at 190 °C with a load of 2,16 kg (symbol D). For thermoplastic polymers with a melt flow rate < 0,1 g/10 min, a test under a load of 5 kg (symbol T) is recommended. If the melt flow rate is still < 0,1 g/10 min, the test should then be carried out under a load of 21,6 kg (symbol G).

The symbols D, T and G shall precede the code for melt flow rate given in Table 7.

Table 6 — Density

Code	**Density** [a] g/cm^3	
	>	⩽
15	—	0,917
20	0,917	0,922
25	0,922	0,927
30	0,927	0,932
35	0,932	0,937
40	0,937	0,942
45	0,942	0,947
50	0,947	0,952
55	0,952	0,957
60	0,957	0,962
65	0,962	—

[a] Density ranges for uncoloured and unfilled polyethylene materials.

Table 7 — Melt flow rate (MFR)

Code	**Melt flow rate** g/10 min	
	>	⩽
000	—	0,1
001	0,1	0,2
003	0,2	0,4
006	0,4	0,8
012	0,8	1,5
022	1,5	3
045	3	6
090	6	12
200	12	25
400	25	50
700	50	100

3.4.4 Polyalkyleneterephthalates

The distinctive property of polyalkyleneterephthalates is the viscosity number according to ISO 7792-1, determined in accordance with ISO 1628-5, and designated by two digits (see Table 8).

Table 8 — Viscosity number for polyalkyleneterephthalate

Polyalkylene-terephthalate	Code	Viscosity number, ml/g	
		>	⩽
PET	**06**	—	60
	07	60	70
	08	70	80
	09	80	90
	10	90	100
	11	100	120
	13	120	140
	15	140	—
PBT	**08**	—	90
	10	90	110
	12	110	130
	14	130	150
	16	150	170
	18	170	—

3.4.5 Other polymers

The coding for the distinctive properties of polyoxymethylene, polytetrafluoroethylene, poly(amide-imide) and polyimide will be included in a future edition of this International Standard.

3.5 Data block 4

The fillers and reinforcing materials, as well as additives specific for the application in plain bearings, are coded as follows:

position 1: types of fillers and reinforcing materials, coded by a letter (see Table 9)

position 2: physical forms of fillers and reinforcing materials, coded by a letter (see Table 10)

positions 3 and 4: mass content of fillers and reinforcing materials, coded by two digits (see Table 11)

positions 5 and 6: fillers in position 1, coded by two letters (see Table 12)

Table 9 — Types of fillers and reinforcing materials (position 1)

Code	Type
C	Carbon
G	Glass
K	Chalk
S	Synthetic organic material
T	Talcum
X	No indication

Table 10 — Physical forms of fillers and reinforcing materials (position 2)

Code	Morphology
D	Powder
F	Fibre
S	Spheres
X	No indication

Table 11 — Mass content (positions 3 and 4)

Code	Mass percentage	
	>	⩽
0X	No indication	
01	0,1 (inclusive)	1,5
02	1,5	3
05	3	7,5
10	7,5	12,5
15	12,5	17,5
20	17,5	22,5
25	22,5	27,5
30	27,5	32,5
35	32,5	37,5
40	37,5	42,5
45	42,5	47,5
50	47,5	55
60	55	65
70	65	75
80	75	85
90	85	—

Table 12 — Fillers (positions 5 and 6)

Code	Type
GR	Graphite
MO	MoS_2 (Molybdenum disulfide)
OL	Mineral oil
PE	Polyethylene
TF	PTFE (Polytetrafluoroethylene)

3.6 Data block 5

For the testing of tribological properties, see ISO 7148-2.

4 Designation examples

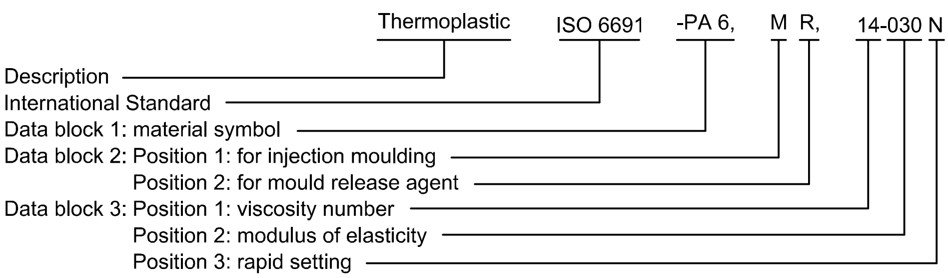
A summary of the designation system is given in Table 13.

Table 13 — Summary of the designation system

Description block	Thermoplastic				
International Standard number block	ISO 6691				
	Data block	Position	Content	Reference Subclause	Reference Table
Individual item block	1	—	Material symbol	3.2	1
	2	1	Intended application or method of processing	3.3	2
		2 to 4	Important properties and/or additives	3.3	3
	3	—	Distinctive properties	3.4	4 to 8
	4	1	Types of fillers and reinforcing materials	3.5	9
		2	Physical forms of fillers and reinforcing materials	3.5	10
		3 and 4	Mass content of fillers and reinforcing materials	3.5	11
		5 and 6	Additional information	3.5	12
	5[a]	—	Tribological properties for plain bearings	3.6	—

[a] See 3.6.

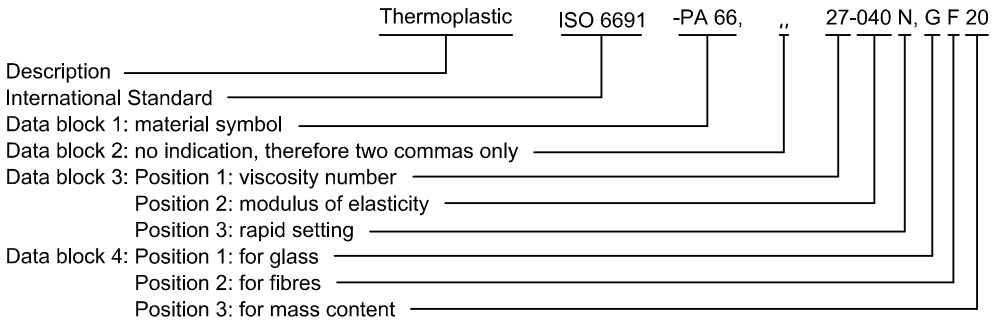
EXAMPLE 1 A polyamide 6 (PA 6), for injection moulding (M) with mould release agent (R), having a viscosity number of 140 ml/g (14), a modulus of elasticity of 2 600 N/mm^2 (030) and rapid setting (N) is designated as follows:



Designation:

Thermoplastic ISO 6691-PA 6, MR, 14-030N

EXAMPLE 2 A polyamide 66 (PA 66), without indications as to use additives in data block 2, having a viscosity number of 280 ml/g (27), a modulus of elasticity of 4 000 N/mm^2 (040), rapid setting (N) and 20 % (*m*/*m*) glass fibre (GF20) is designated as follows:



Designation:

Thermoplastic ISO 6691-PA 66, ,, 27-040N, GF20

5 Ordering information

The purchaser and supplier shall agree on the tests to be carried out.

If mechanical and/or tribological properties are to be tested, it shall be agreed whether such tests are carried out on

a) unmodified parts of the delivered goods,

b) test bars, manufactured from the same batch, or

c) test bars taken from a finished part to be supplied,

and whether the test shall be carried out parallel or perpendicular to the flow direction and/or machining direction.

Annex A
(informative)

Properties and applications of the most common unfilled thermoplastic polymers

A.1 Properties and applications of unfilled thermoplastic polymers

Table A.1 gives an outline of the properties and applications of unfilled thermoplastic polymers most commonly used for plain bearings.

Table A.1 — Outline

Group of thermoplastic polymers (symbol)	General description	Chemical properties	Examples of application
Polyamide (PA)	Resistant material, extraordinarily shock- and wear-resistant, good damping properties. High sliding resistance in dry running. Relatively high moisture absorption.	Resistant to fuels, oils, and greases and to most common solvents. Sensitive to mineral acid even in dilute solution, but not attacked by strong alkalis even at high concentrations. The use of PA 6 and PA 66 in hot water requires formulations that are stabilized against hydrolysis. PA 11 and PA 12 are widely resistant to hydrolysis.	Bearings subjected to shock and vibration. Guide blocks in steel mill couplings. Bushes for brake rods in wagon construction. Bearings for agricultural machinery. Spring eye bushes.
Polyoxymethylene (POM)	Hard material; therefore higher resistance to pressure than polyamide, but more sensitive to shock. Less wear-resistant but smaller coefficient of friction than polyamide. Very low moisture absorption.	High resistance to numerous chemicals, above all to organic liquids. Only a few solvents can dissolve POM. Even at high temperatures POM-copolymer withstands strong alkaline solutions such as 50 % NaOH. Chemicals having an oxidizing effect and strong acids (pH < 4) attack POM.	Plain bearings having strict requirements concerning dimensional stability and coefficient of friction. Good for dry running or for deficient lubrication. Plain bearings for fine mechanics, electromechanics and household appliances.
Polyethyleneterephthalate (PET) Polybutyleneterephthalate (PBT)	Hardness similar to that of POM; however, decreases considerably above 70 °C. Up to 70 °C, wear and coefficient of friction very low. Low moisture absorption.	Good weather resistance and high resistance to numerous solvents, oils, greases, and salt solutions. Sufficiently resistant to many acids and alkalis in aqueous solution. Attacked by concentrated inorganic acids and alkalis. Halogenated hydrocarbons such as methylene chloride and chloroform lead to high swelling. Sensitive to hydrolysis at high temperatures.	Application for plain bearings similar to POM. Mostly for plain bearings at temperatures below 70 °C. Good for dry running and for deficient lubrication. Plain bearings for fine mechanics and submerged installations, guide bushes for rods. Plain bearings for oscillating movements.

Table A.1 (*continued*)

Group of thermoplastic polymers (symbol)	General description	Chemical properties	Examples of application
Polyethylene with ultra high molecular weight (PE-UHMW) High density polyethylene (PE-HD)	PE-UHMW has high shock resistance. PE-HD has low resistance to permanent pressure. However, it is resistant to shock. About twice the thermal expansion of PA and POM. Excellent wear resistance against abrasive stresses. Good sliding and bedding characteristics. No moisture absorption. Resistant to low temperatures.	At room temperature, PE is inert to water, alkaline solutions, salt solutions, and inorganic acids (except strongly oxidizing acids). At room temperature, polar liquids such as alcohols, organic acids, esters, ketones, and the like only result in slight swelling. Aliphatic and aromatic hydrocarbons and their halogen derivatives are absorbed more strongly, resulting in a decrease in strength. After the diffusion of these media, polyethylene can regain its original properties. Non-volatile liquids such as greases, oils, waxes, etc. are less active.	Plain bearings for installation in waters carrying sand. Road and agricultural machinery construction. Bearings for low temperatures. Plain bearings in chemical installations.
Polytetrafluoroethylene (PTFE)	Resistant to shock, has good bedding characteristics and can be used for dry running. Under high load and slow sliding velocity, low coefficient of friction. Anti-adhesive; can be used at high and low temperatures. No moisture absorption. Unfilled PTFE is less resistant to wear; it is mostly used for confined bearings.	At temperatures below 260 °C, is not attacked by chemicals, except by dissolved or molten alkali or alkaline earth metals. Elemental fluorine or chlorine fluoride attack above room temperature.	Plain bearings in chemical installations, high-frequency engineering, application at high temperatures or very low coefficients of friction. Bridge bearings and similar bearings with very low sliding velocities (crawling velocity). For plain bearings used in the foodstuff sector unfilled PTFE is physiologically harmless.
Polyimide (PI)	High-temperature material, with high hardness. Low wear. Relatively high coefficient of friction in dry running at sliding surface temperatures below 70 °C. High load-carrying capacity. Low moisture absorption. Also suitable for use at very low temperatures.	Resistant to most of the aliphatic and aromatic hydrocarbons, to diluted or weak acids and to oils and fuels. Depending on concentration and temperature, alkaline solutions are attacking. When used in hot water or steam, hydrolysis has to be taken into account.	Plain bearings in tunnel furnaces.
Polyetheretherketone (PEEK)	PEEK is a semi-crystalline thermoplastic polymer and a high-temperature material with high tensile and bending strength. Due to the extraordinary fatigue strength under reversed bending stresses under cyclic loading it has a long life. The material has excellent resistance to hydrolysis.	The material is resistant to most chemicals. The product is only dissolved by concentrated sulfuric acid. Nitric acid and some halogenated hydrocarbons decompose the material.	Plain bearings and sliding elements under heavy conditions up to 250 °C. The very advantageous tribological behaviour in itself can be considerably improved by addition of PTFE graphite and carbon fibres.
Polyvinylidene fluoride (PVDF)	This fluoroplastic has PTFE-allied properties, yet higher mechanical strength, rigidity and viscosity. The temperature limit in use is 150 °C. The creep tendency is distinctly restricted in comparison with PTFE.	Resistant to acids, alkalis, solvents and chlorinated hydrocarbons, hot acetone, ketones and esters. Not resistant to primary amines at higher temperatures. No objection against use in contact with foodstuff. The material is physiologically nontoxic.	Plain bearings in chemical installations — machines for foodstuff production.

Table A.1 (*continued*)

Group of thermoplastic polymers (symbol)	General description	Chemical properties	Examples of application
Polyphenylene sulfide (PPS)	Without additions PPS is a relatively brittle high-crystalline thermoplastic polymer. The temperature of use is up to 220 °C. The relatively high coefficient of friction of 0,4 to 0,7 is decreased by additives, and impact resistance and fatigue strength under reversed bending stresses are improved.	Excellent resistance to chemicals — when used below 200 °C no solvents are known to attack. Not resistant to chlorosulfonic acid. The material is resistant to hydrolysis.	Plain bearings in contact with chemicals at high temperatures and under heavy conditions.
Poly(amide-imide) (PAI)	High performance thermoplastic of exceptional strength for use at extremely high and extremely low temperatures, high fatigue strength, extremely favourable wear characteristics. PAI parts require post-curing in order to achieve optimum wear and chemical resistance.	Excellent chemical resistance. At increased temperature (93 °C) PAI is attacked by phenylsulfonic acid, formic acid and soda lye (30 %). Above 160 °C steam (water vapour) leads to degradation.	Plain bearings and slide elements for high load and temperatures up to 260 °C. The tribological behaviour can be improved by additives of PTFE or graphite.

A.2 Characteristic properties in plain bearing applications

The characteristic properties for thermoplastic polymers used for plain bearings in tribological systems are their behaviour under compressive stress, their resistance to temperature and moisture, as well as their heat conductivity and sliding characteristics including wear resistance.

The tribological system depends not only on the properties of the plain bearing material, but also on the type and surface of the mating partner, the type of application, the design, the environmental influences, the general working conditions, and, if applicable, the lubricant. (See also annex B.)

Table A.2 and Figure A.1 show approximate values of these parameters.

The actual values can deviate within the groups of thermoplastic polymers according to the type of plastic used and the manufacturer's grades. Depending on the application, other properties should also be considered.

A.3 General properties

In addition to the properties referred to in A.1 and A.2, other thermoplastic properties are important for plain bearings applications.

Table A.3 gives some values for guidance for such properties. The actual values may differ widely depending on the thermoplastic polymer used and on the type of processing (within each group).

The wear of the thermoplastic plain bearing depends to a large extent on the accuracy of the geometrical shape.

Table A.2 — Characteristic properties for unfilled thermoplastic polymers in plain bearings

Characteristic properties for thermoplastic polymers			Material															
			PA 6	PA 6 cast	PA 66	PA 12	PA 12 cast	PA 46	POM	PET	PBT	PE-UHMW	PTFE[a]	PI[b]	PEEK	PVDF	PPS	PAI
Sliding behaviour[c d]			See Figure A.1															
Wear resistance[d]			See Figure A.1															
Recommended mating material	Mating from metal[e]	Hardness (HRC), min.	50	50	50	50	50	50	50	50	50	50[e]	50[e]	50[e]	50	50	50	—
		Roughness, *Rz* (µm)	2 to 4	2 to 4	2 to 4	2 to 4	2 to 4	2 to 4	1 to 3	0,5 to 2	0,5 to 2	0,5 to 2	0,2 to 1	2 to 4	2 to 4	1 to 3	1 to 3	—
	Mating from thermo-plastic	Thermoplastic and thermoplastic modified[f]	POM POM mod.	POM POM mod.	POM POM mod.	POM POM mod.	POM	PA PA mod.	PA PBT POM mod.	POM	POM	PA	PA POM PET PBT	—	—	—	—	—
		Roughness[g] (µm) *Rz*	10	10	10	10	10	10	10	10	10	10	5	—	—	—	—	—
		Roughness[g] (µm) *Ra*	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	0,8	—	—	—	—	—
Equilibrium moisture content [%(*V*/*V*)]	at standard atmosphere[h]		2,5 to 3,5	2,2 to 3	2,2 to 3,1	0,7 to 1,1	0,4 to 0,9	2,8	0,2 to 0,3	0,3	0,2	0	0	1 to 1,3	1 to 1,3	0,05	0,03	1,8 to 2,5
	in water at 20 °C[i]		9 to 10	7 to 9	8 to 9	1,3 to 1,7	1,3 to 1,5	9,5	0,6 to 0,7	0,6	0,5	0	0	—	—	0,05	0,09	—
Temperature limits (°C)	Melting temperature (ISO 1218 and ISO 3146)		215 to 220	210 to 220	250 to 260	175 to 180	186 to 192	295	165 to 184	255 to 260	220 to 225	130 to 178	327	j	340	175	280	j
	Vicat softening temperature (ISO 306:1994, method A; PA 12 cast, method B)		180	—	299	165	190 (method B)	—	163 to 173[k]	188	178	70	110	—	—	—	—	—
	Short-time working temperature		140	150	160	140	140	250	120 to 140	180	165	110	300	300 to 480	310	160	260	260
	Constant working temperature[l]		80 to 100	80 to 100	80 to 100	70 to 100	80 to 110	135 to 155	80 to 100	60 to 100	70 to 100	250	260	250	250	150	220	260
Pressure limits[m] (N/mm^2) (see Figure A.1)	Ball pressure hardness 30 s (ISO 2039-1)[n]		55	55	65	70	100	—	125	155	130	40	30	—	—	—	—	—
	Continuous (static)		12	13	14	11	12	—	18	19	18	8	5	20	—	—	—	—

a The figures apply to unfilled PTFE. Unfilled PTFE is only used for plain bearings where the design keeps it from creeping (confined sliding elements). Filled PTFE compounds are generally used: they are more resistant to compression and wear.

b Polyimides are mostly used with fillers: because of this and of the wide range of the polyimide class, it is impossible to designate these materials here in detail.

c See B.3.4 (lubrication)

d The values shown on Figure A.1 apply to unfilled thermoplastics. They may change considerably when fillers are added to the specified thermoplastics.

e See B.3.3 (mating partner).

f Examples of common modifying filler materials: PE, PTFE, MoS_2, graphite, chalk.

g See B.3.3.4 (counterface roughness).

h A method for determining the equilibrium moisture content in standard atmosphere 23/50 (23 °C air temperature, 50 % relative humidity) is given in ISO 291.

i Determination of water absorption in accordance with ISO 62.

j Most do not melt below decomposition temperature.

k The upper temperature applies to homopolymer.

l See B.3.7 (temperature).

m At equilibrium moisture content in standard atmosphere 23/50. See also B.3.5 (compression stress).

n Since the new test methods now specify only the 30 s value instead of the former 10 s and 60 s values, it is suggested that the 1 h value also be tested if information on creep behaviour is important.

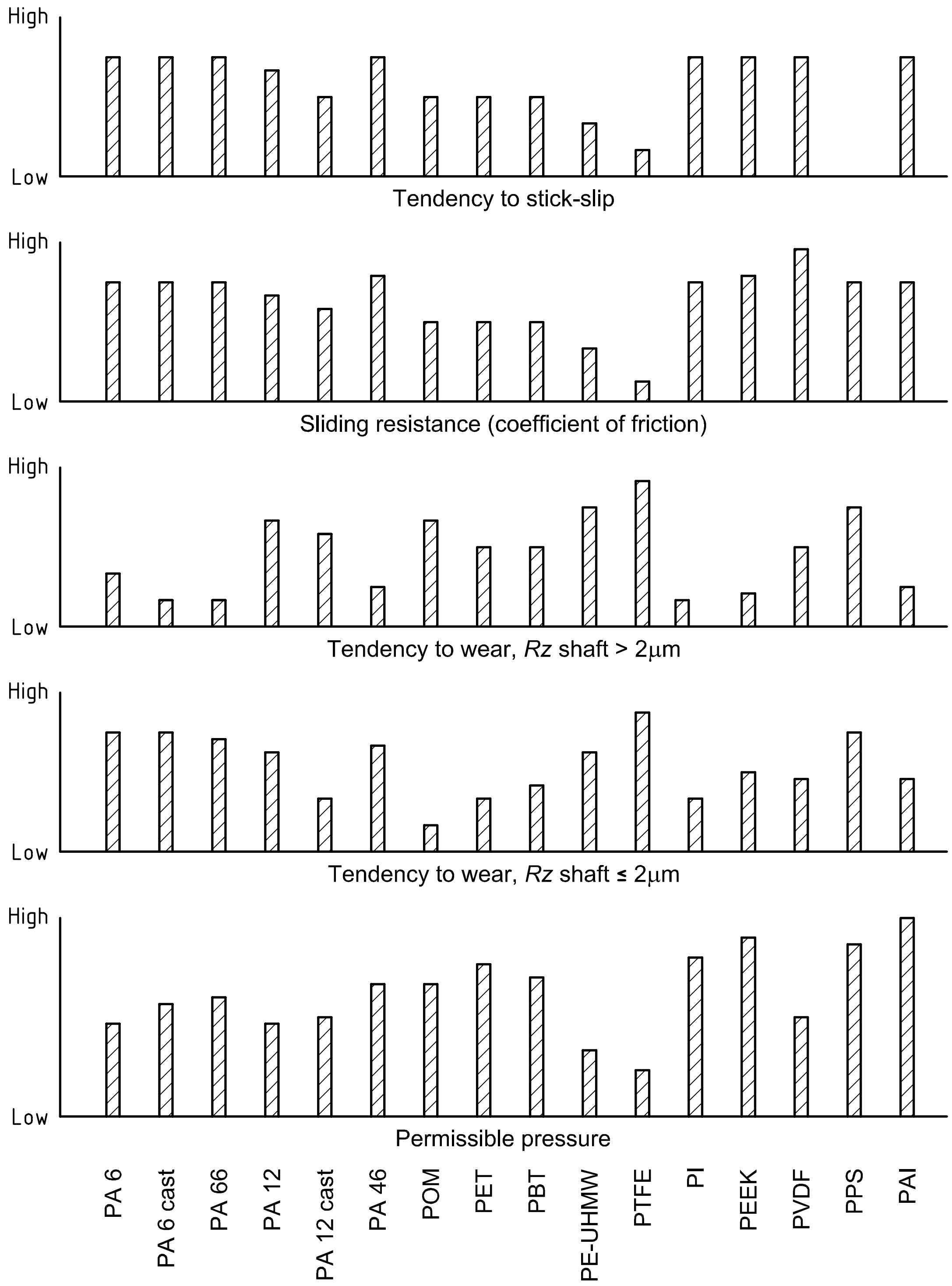


Figure A.1 — Typical behaviour of some unfilled thermoplastic polymers when used in plain bearings sliding at low velocity against steel, without lubrication (relative comparison)

Table A.3 — General properties for unfilled thermoplastic polymers in plain bearings

General properties for thermoplastic polymers		Material															
		PA 6	PA 6 cast	PA 66	PA 12	PA 12 cast	PA 46	POM	PET	PBT	PEUHMW	PTFE	PI	PEEK	PVDF	PPS	PAI
Density (g/cm^3)	dry	1,13	1,13	1,14	1,02	1,03	1,18	1,41	1,37	1,29	0,94	2,15	1,43	1,32	1,78	1,35	2,41
Tensile strength	dry	50 to 80	50 to 85	80 to 90	50	55	100	65 to 72	70	60	20 to 38	7 to 15	85	92	54	80	192
(yield point) (N/mm^2)	moist	40 to 50	40 to 60	55 to 60	40	45	55	—	—	—	—	—	—	—	—	—	—
Elongation at break (%)	dry	130	10	40	250	150	25	25 to 70	50	200	450	300	—	50	80	15 to 25	15
	moist	220	70	150	280	200	100	—	—	—	—	—	—	—	—	—	—
Limiting bending stress (N/mm^2)	dry	120	140	125 to 130	70	90	150	100 to 105	130	105	27	16 to 20	—	170	74	150	244
	moist	50	60	60	—	—	50	—	—	—	—	—	—	—	—	—	—
Modulus of elasticity (tensile) (N/mm^2)	dry	2 600	2 700	2 800	1 900	2 400	3 100	2 800 to 3 200	3 000	2 800	790	700	3 400	3 600	1 800	400	4 400
	moist	1 400	1 500	1 600	1 600	2 100	1 500	—	—	—	—	—	—	—	—	—	—
Notch impact strength (kJ/m^2)	dry	3 to 6	1,5 to 3	3 to 5	10 to 17	5 to 15	6	6 to 9	6	3 to 6	No break	16	—	6	14	3	11
	moist	No break	30	20 to 80	25	15	25	—	—	—	—	—	—	—	—	—	—
Impact strength (kJ/m^2)	dry	No break															
	moist																
Coefficient of linear thermal expansion ($10^{-6} \cdot K^{-1}$)	dry	85	75	85	110	100	90	120	80	60	—	100 to 160	31	47	130 to 170	50	30
Coefficient of thermal conductivity [W/(m·K)]	dry	0,23	0,23	0,23	0,29	0,29	0,3	0,31	0,26	0,27	0,41	0,23	0,3	0,25	0,19	0,3	0,26
Electrical disruptive strength (kV/mm)	dry	50	50	50	33	35	60	70	89	109	90	50	—	25	20	21	23,6
	moist	20	20	41	32	30	20	—	—	—	—	—	—	—	—	—	—

Annex B
(informative)

Fundamental application procedures

B.1 General

This annex lists some of the fundamental parameters that influence the selection of thermoplastic polymers for use for plain bearings.

However, it is by no means sufficiently comprehensive for the final selection, calculation and design of thermoplastic plain bearings. Definitive information should be obtained from the suppliers of plain bearings or raw materials.

B.2 Selection and application of thermoplastics used for plain bearings

The thermoplastic polymers referred to in this International Standard fulfil, to various degrees, the requirements for plain bearings application, such as the following:

a) low coefficient of friction;

b) high resistance to wear;

c) adequate load-bearing ability;

d) adequate temperature stability;

e) emergency running ability.

In addition, the following properties, which depend on the type of thermoplastic polymer used, should be mentioned, even though a wide range of characteristics may be given:

f) dry-running ability;

g) whether it is maintenance-free (in many cases one lubrication during assembly will suffice);

h) interaction with the environmental medium (such as water, lyes, acids, etc.) which may function as lubricant or coolant, depending on the chemical resistance of the plain bearing thermoplastic;

i) whether it is smooth running;

j) ability to absorb vibrations and impacts;

k) resistance to corrosion;

l) resistance to chemicals;

m) whether it is of low toxicity;

n) insulation;

o) whether it is of low mass.

The thermoplastic plain bearing with the mating partner, the lubricant and the environmental influences form a tribological system the field of application and service conditions of which are mainly determined by the temperature (ambient temperature + temperature rise due to friction). Figures B.1 and B.2 show the dependence of the mechanical values of thermoplastic polymers on temperature using the example of the modulus of elasticity.

B.3 Influences of system and environment

B.3.1 Plain bearing type

Depending on the type of thermoplastic polymer, unlubricated radial bearings give a value of $p{\cdot}u$ between two and four times better than thrust bearings.

B.3.2 Kind of motion

In instruments, thermoplastic plain bearings are mainly used to support rotating shafts. In machines and vehicles, they are mainly used to absorb oscillating and reciprocating motions.

The different stresses between rotating, oscillating and reciprocating movement and between continuous and intermittent operation have an important influence on the permissible value of $p{\cdot}u$ and on wear.

B.3.3 Mating partner

B.3.3.1 Material

Hardened steel is the most suitable material as mating partner for thermoplastic polymers. Glass is also suitable. Mating partners made of non-ferrous metals can be used as well but the following points have to be taken into account:

a) the coefficient of friction is higher if the surface hardness is < 50 HRC;

b) sliding wear may increase;

c) the permissible value of $p{\cdot}u$ and the wear resistance are lower even though the heat conductivity is better than that of steel.

PE shows reasonable sliding properties when running with a mating partner made from copper alloys. PTFE shows reasonable sliding properties when running with a mating partner made from copper alloys; however, it should not be used when running with a mating partner made of aluminium alloys unless the surface is hard anodized.

If a thermoplastic polymer runs with a plastic partner instead of a metallic one, lower and constant friction can be achieved.

Table A.2 gives suitable matings.

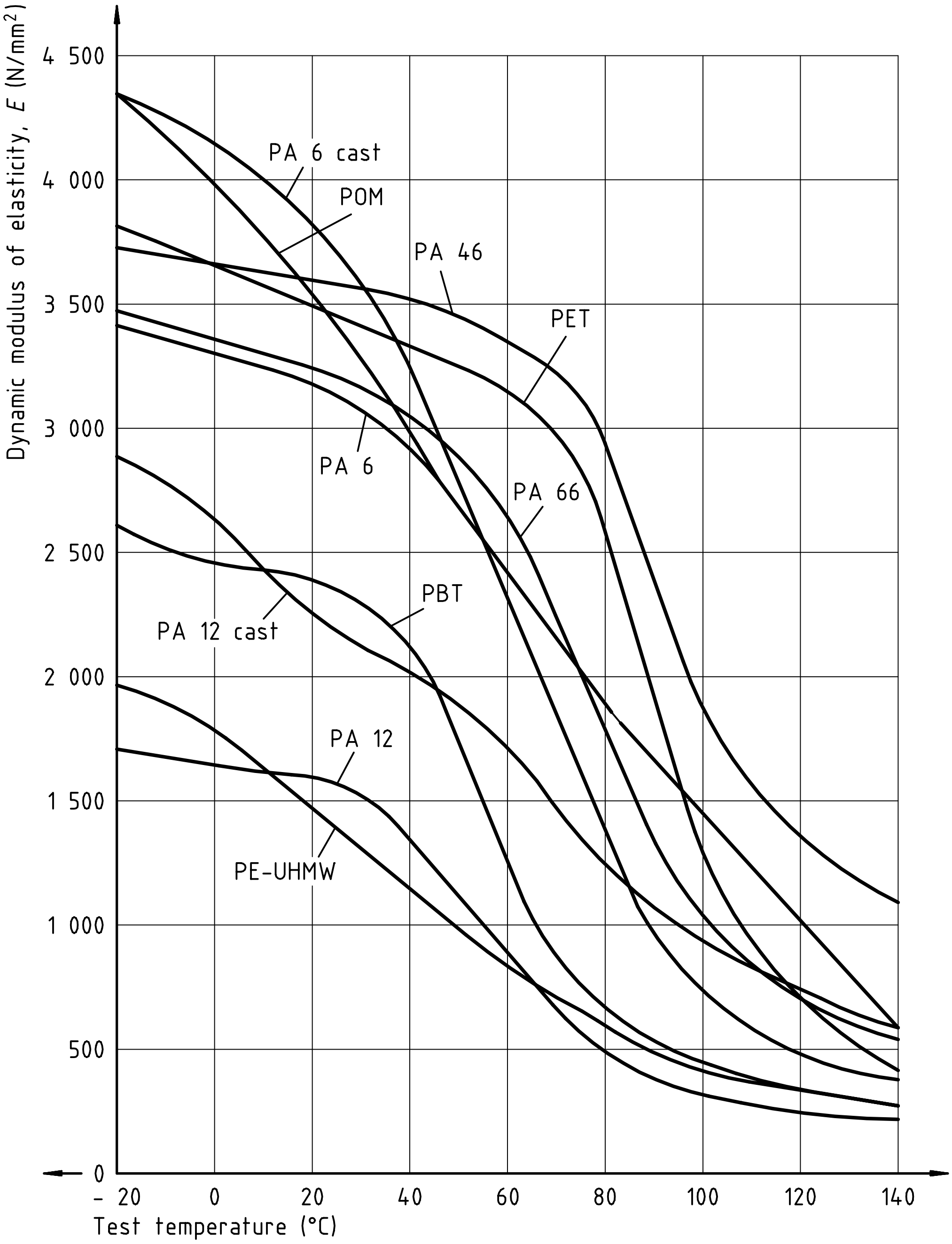


Figure B.1 — Dynamic modulus of elasticity versus temperature (mass moisture content of specimen < 0,2 %) for thermoplastics PA 6, PA 6 cast, PA 66, PA 12, PA 12 cast, PA 46, POM, PET, PBT and PE-UHMW

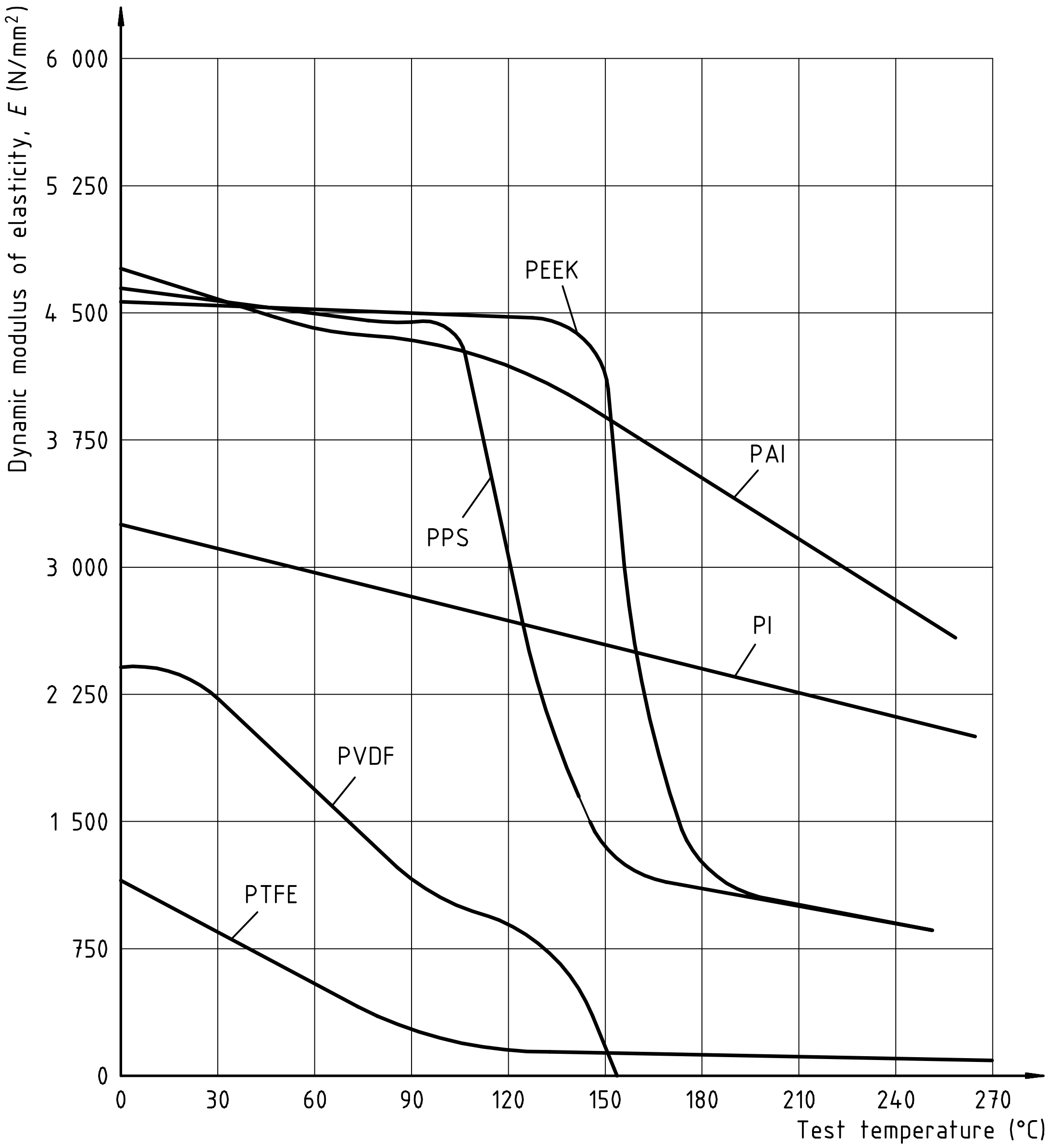


Figure B.2 — Dynamic modulus of elasticity versus temperature (mass moisture content of specimen < 0,2 %) for thermoplastics PTFE, PI, PEEK, PVDF, PPS and PAI

B.3.3.2 Hardness

The best sliding conditions (factors of wear) are achieved if the Rockwell hardness of the surface of the metallic partner is > 50 HRC, irrespective of the type of thermoplastic polymer.

B.3.3.3 Roughness of the metal partner

In general, the smoother the sliding partner, the lower the wear of the thermoplastic bearing. The coefficient of friction increases with decrease in the roughness of the sliding partner.

B.3.3.4 Roughness of the thermoplastic partner

Unlike the values given in Table A.2 for fine mechanics (for example instruments), roughness values of $Rz \leqslant 2\ \mu m$ are recommended.

B.3.4 Lubrication

Thermoplastic plain bearings complying with this International Standard can run dry, but they may also be lubricated with oil, grease, and some other fluids (assuming chemical compatibility: see Table A.1). In certain cases water may be used.

Lubricated plain bearings can withstand a higher tribological stress. The limit of the tribological stress depends on the respective friction condition (boundary friction, mixed friction, fluid friction). When using lubricants, stick-slip symptoms and fretting corrosion are reduced. Furthermore, it is possible to apply solid lubricants to the sliding surfaces from the outside, for example, polytetrafluoroethylene, graphite and molybdenum disulfide. Also in the case of bearings which normally run dry, a unique lubrication during mounting is recommended for the running-in period.

Thermoplastic polymers must be resistant to the lubricant (ageing characteristics must be taken into account). (See ISO 175.)

B.3.5 Compression stress

The strength under compression of thermoplastic plain bearings is lower than that of most metallic plain bearings.

For short-term compression stress (dynamic loads), see B.3.10.

The continuous pressure limits given in Table A.2 apply to unconfined plain bearings at standard atmosphere. Rising temperature (friction) results in a lower permissible load.

B.3.6 Velocity

Thermoplastic polymers are bad heat conductors. If frictional heat cannot dissipate elsewhere (for example via the mating partner), the permissible range of the sliding (frictional) velocity is limited by the heat conductivity of the wall of the bearing.

B.3.7 Temperature

The permissible temperatures for continuous use are considerably lower than the short-term thermal stabilities. The values for continuous use as given in Table A.2 mean that at such temperatures the properties will for years not alter more, by thermal ageing, than is permissible for technical parts in general applications (see also ISO 2578) and that the mechanical strength will be approximately half less than that at room temperature.

The thermal expansion of thermoplastic polymers is about ten times higher than that of steel, implying a greater bearing clearance. The mechanical values vary as a function of temperature. The poor thermal conductivity of thermoplastic polymers compared to that of metal limits the dissipation of frictional heat.

B.3.8 Moisture

The values of water absorption given in Table A.2 are valid at room temperature. Higher temperatures result in a greater moisture absorption. The moisture absorption effects a gradual change in linear dimensions which may reach 1/3 to 1/4 depending on the water absorbed (in percent). The moisture absorbed modifies the mechanical properties of thermoplastic polymers.

B.3.9 Time

Under long-term working conditions thermoplastic polymers tend to creep. It is therefore recommended to increase the indexes, up to a maximum of approximately 1/5 of the short-term indexes, for continuous compression or tensile stress.

B.3.10 Dynamic loads and vibrations

Thermoplastic polymers are in general able to withstand short-term dynamic stress very well, unlike continuous loading. When subjected to vibration, their performance may decrease to about 50 % to 70 % of the short-term values.

B.3.11 Chemicals

The plain bearing materials and the lubricants vary strongly in their chemical resistance. It is recommended that the supplier be consulted if the kind of application is critical.

B.3.12 Biological interactions

When using plain bearings in the fields of food, stimulants, medicine and pharmacy, official regulations shall be strictly observed.

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ICS 21.100.10; 83.080.20

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