PART 3. TECHNOLOGICAL PROPERTIES OF MATERIALS

Materials

CHAPTER VI

Article 26 Cements

26.1 Usable cements

The cements that may be used within the framework of this Instruction are those that comply with the current Instruction for the Acceptance of Cements, of strength class 32.5 or higher, and comply with the limitations set out in Table 26.1. The cement shall be capable of providing concrete with the qualities required in Article 30

Table 26.1

Type of concrete	Type of cement
Mass concrete	Common cements Special purpose cements
Reinforced concrete	Common cements
Prestressed concrete	Common cements of types CEM I and CEM II/A-D

Common cements and special purpose cements are standardised in UNE 80301:96 and UNE 80307:96, respectively.

In Table 26.1, the use of common cements, for each type of concrete, should be considered as extending to white cements (UNE 80305:96) and cements with additional properties (sulphate and sea water resistance in accordance with UNE 80303:96, and low heat of hydration according to UNE 80306:96) corresponding to the same types and strength classes

When the cement is used as an injection product, the provisions of 36.2 shall be taken into account.

Before calcium aluminate cement is used, a special study shall be carried out in each case in order to establish the reasons that make its use advisable, and also taking into account the specifications contained in Annex 4.

The provisions of 30.1 shall be taken into account with regard to chloride ion content.

For the purposes of this Instruction, slow-hardening cements are those in strength class 32.5, normal-hardening cements are those in classes 32.5R and 42.5, and early-hardening cements are those in classes 42.5R, 52.5 and 52.5R.

COMMENTS

Special purpose cements are mainly indicated for large blocks of mass concrete, together with other uses, particularly in the construction of road pavements. This type of cement should not be employed for reinforced or prestressed concrete.

The paragraph that deals with white cements and cements with additional properties means that, in addition to cement type CEM I and CEM II/A-D, only white Portland cement type BLI, and the CEM I and CEM II/A-D cements with additional properties of sulphate resistance (SR) , sea water resistance (MR) or low heat of hydration (BC) may be employed.

In general, and particularly when it is to be employed in the construction of precast elements, it is advantageous for the cement to have suitable properties to allow that concrete may be subjected to hygrothermal or other similar treatment, in order to accelerate its setting and hardening.

The cement type should be selected taking into account , among others factors, , the end use of the concrete, the environmental conditions to which the concrete is to be exposed, and the dimensions of the section. It is therefore advisable to follow the general recommendations for the use of the cements which are included in Annex 3 of this Instruction.

26.2 Supply

At cement delivery, the supplier shall provide a delivery document (ticket) with the information required by the current Instruction for the Acceptance of Cements, which establishes the supply and identification conditions that the cements must meet in order to be accepted.

When supplied in bags, the cement shall be received in the same closed containers in which it was dispatched from the factory, depot, dispatching centre or distribution warehouse.

The cement shall not arrive at the site, or other place where it is to be employed, in excessively hot conditions. It is recommended that the temperature should not exceed 70°C if it is to be handled by mechanical means, or 40°C if it is to be handled manually.

If it appears that false setting might occur, checks, in accordance with UNE 80114:96, shall be performed before the cement is used to ensure that it does not have a tendency to undergo this phenomenon.

COMMENTS

During hot weather, or when the concreting temperature is high, a natural setting acceleration occurs, which should not be confused with false setting.

False setting is a phenomenon that may be produced when high temperatures are reached (exceeding 100ºC) during cement grinding, which can potentially lead to the cement undergoing a rapid paste rigidity, leading to more water being added incorrectly to the concrete. This false setting will disappear without any consequences or need to add more water , simply by more energetic mixing of the concrete.

When the concrete is to be employed in large blocks, a high cement temperature (as with the other components in the concrete) is a negative factor that should be taken into consideration.

26.3 Storage

When the cement is supplied in bags, these should be stored in a well-ventilated place, protected from both the weather and dampness from the floor and walls. If it is supplied in bulk, then it should be stored in silos or other containers that provide protection from moisture.

Even when storage conditions are good, cement should not be stored for a long period of time, since it may deteriorate. The maximum recommended storage time is three months, two months and one month, respectively, for strength classes 32.5, 42.5 and 52.5. If it is stored for longer, a check should be made to ensure that the cement properties are still suitable. For this reason, during the twenty days before use, tests to determine the initial and final setting times and initial mechanical strength at 7 days (for class 32.5) or 2 days (for all other classes) should be performed on a representative sample of the stored cement, without excluding any lumps that might have formed.

In all cases, except when the new setting period is incompatible with the particular site conditions, the suitability of the cement at the time of use will be finally confirmed by the results of determining, in accordance with Article 88, the 28-day mechanical strength of the concrete produced with it.

COMMENTS

Even in those situations where the storage conditions are excellent, a long storage period may cause cement strength losses, together with an increase in setting time, and this is the motive for the prescribed tests.

If the setting tests results are compatible with the particular site conditions (which might not occur where frosts are a danger, for example), cement can continue be employed if the strength loss is compensated with a higher cement content in the concrete. However, the cement content increase will be limited by a maximum of 400 kg/m^3 prescribed in a general manner in Article 68, or eventually, by another stricter figure that could be stated in the Project Specification.

To determine the new concrete composition, the results from the prescribed strength tests are very useful because, in general, the cement strength loss percentage is approximately the same at 28 days and at 7 days.

In this way, it is possible in many cases for the concrete strength to continue to be suitable, which, ultimately, is the determinant factor on whether to employ the cement or not.

Article 27 Water

The water used both for mixing and for curing the concrete on site shall not contain any harmful ingredients in such quantities as may be detrimental to the properties of the concrete or to the reinforcement corrosion protection. In general, any waters shown by practice to be acceptable may be used.

Where there is no history of usage or where any doubt exists, the waters shall be analysed and, unless it can be shown that they will not have a detrimental effect on the properties required of the concrete, they shall meet the following requirements.

- hydrogen exponent pH (UNE 7234:71) ≥ 5
- dissolved substance (UNE 7130:58) $\leq$ 15 grams per litre (15,000 ppm)
- sulfate content as $SO_4^{=}$ (UNE 7131:58), except for SR cement for which this limit is raised to 5 grams per litre (5,000 p.p.m) $\leq$ 1 gram per litre (1,000 p.p.m)

- chloride content, Cl^- (UNE 7178:60):

- for prestressed concrete	≤ 1 gram per litre (1,000 p.p.m)
- for reinforced concrete or mass concrete containing steel to reduce cracking	≤ 3 grams per litre (3,000 p.p.m)

- carbohydrates (UNE 7132:58) 0
- ether-soluble organic substances (UNE 7235:71) ≤ 15 grams per litre (15,000 p.p.m)

the samples shall be taken in accordance with UNE 7236:71 and the analyses using the methods of the above mentioned standards.

Sea water or similar salt waters may, however, be used for mixing and curing concretes that do not contain any reinforcement. Except for special studies, the use of such waters for mixing or curing reinforced or prestressed concrete is expressly forbidden.

The provisions of 30.1 shall be taken into account with regards to chloride ion content.

COMMENTS

The use of sea water reduces concrete strength (by approximately fifteen percent). Its use therefore, is only allowed in concrete without any reinforcement, and should be conditioned, not only to whether the stains that usually appear when it is used, but also to whether the concrete meets the required strength specifications. In these cases, it recommended to use a cement with additional MR or SR properties.

The maximum chloride content limit, expressed in chloride ion, is a preventive measure against possible corrosive action on the reinforcement. This limitation affects reinforced and prestressed concretes, as well as mass concretes, but which contains reinforcement to prevent cracking.

Ether-soluble organic substances include not only fats and oils of any origin, but also other substances that might adversely affect the setting and hardening of concrete.

Article 28 Aggregates

28.1 General

The nature of the aggregates and their preparation shall be such that they ensure suitable strength and durability of the concrete and any other characteristics that may be required in the Project Specification.

The aggregates that can be used in concrete are sands and gravels from natural deposits, suitable crushed rock or blast-furnace slag, and other products the use of which is recommended by practice or is advisable as a result of laboratory studies. In all cases, the aggregate supplier shall provide documentary guarantee that the aggregates are conforming with the requirements of 28.3 before they are accepted.

Where there is no existing experience regarding the nature of the aggregates available or they are to be used for applications other than those already proven in practice, identification tests shall be performed by means of mineralogical, petrographic, physical or chemical analyses, as appropriate for each case.

If air-cooled blast-furnace slag is used as aggregate, it shall first be checked for volume stability, i.e. it should not contain unstable silicates or ferrous compounds.

The use of aggregates containing oxidizable sulphides is forbidden.

Aggregates should be transported and stored in such a way that prevents segregation and contamination; they must maintain the grading characteristics of each of their fractions until they are added to the mix.

Whenever there is any doubt, the concrete producer, who is obliged to employ aggregates that comply with the requirements of 28.3., should carry out the corresponding tests.

COMMENTS

The third paragraph of the section requires aggregate identification tests to be performed when there is no previous background information or sufficient experience in its use. Such identification tests should reveal any possible problems that might arise from the use of the aggregates under study. In all cases, it should be remembered that, in accordance with 81.3.2., the tests for identification, and for physical-chemical, physical-mechanical and grading characteristics, as specified in Article 28, shall always be performed, except where exists a certification of the aggregate suitability that comply with the established conditions.

The Instruction prescribes the use of UNE EN 933-2:96 in relation to the determination of the particle grading of the aggregates, with the establishment of the following set of sieves: 0.063 – 0.125 – 0,250 - 0.500 – 1 – 2 – 4 – 8 – 16 - 31.5 – 63 - 125 mm. For fine aggregate, the Instruction only uses the sieves of this series. For coarse aggregate, 10 – 20 – 40 mm sieves are also employed, which are included in the complementary series R 20, accepted by this standard, and which also has a long tradition of use in Spain.

The aggregates shall not react with the cement, nor shall they disintegrate due to the effects of outside agents to which they are subjected to at the site. Therefore, those aggregates from soft, friable, and porous rocks, or those that contain limestone nodules, ferrous compounds or oxidizable sulphides should not be employed, etc.

Among the tests methods for aggregates, there are some of general interest, for example, that used to determine the organic material content, since this is always harmful to concrete setting and hardening.

In other tests, the result is of true interest only in a certain number of cases, since the final objective is to provide a behaviour index for the material under circumstances which, although they may be relatively frequent, are not common to all works. This occurs with the determination of the percentage of loss of mass in a solution of sodium or magnesium sulphate, the main aim of which is to provide information on the freeze resistance of the aggregate employed in the concrete.

The oxidizable aggregates (for example, pyrrhotite, marcasite and some forms of pyrites), even when present in small quantities, may be dangerous in the concrete, due to oxidation and later hydration forming sulphuric acid and hydrated iron oxide, with a great increase in volume.

Certain types of silica rocks (for example, opal and dacites), together with others that contain magnesium carbonate substances (for example, dolomite), which could cause strongly expansive phenomena under certain hygrothermal conditions and in the presence of alkalis coming from the concrete constituents (aggregate – alkali reaction). Other types of harmful reactions may present themselves between the calcium hydroxide released from cement hydration and aggregate that come from certain magmatic or metamorphic rocks in function of their nature and alteration state. For this reason, when there is no experience in usage, it is recommended that identification tests are carried out by a specialised laboratory.

28.2 Aggregate designation and sizes

Aggregates shall be described by their lower sieve size *d* and the upper sieve size *D* in mm, using the following designation: aggregate *d/D*

The upper sieve size *D* of an aggregate is the smallest sieve mesh size in accordance with UNE-EN 933-2:96, that passes more than 90% by mass (less than 10% rejected larger than *D*) while 100% passes through a sieve of double the mesh size (0% rejected larger than 2*D*). The lower sieve size *d* of an aggregate is the largest mesh size in accordance with UNE-EN 933-2:96, that passes less than 10% by mass (less than 10% rejected smaller than *d*). See table 28.2.

Table 28.2 Limits for oversize and undersize

Oversize (% retained, by mass)		Undersize (% passing, by mass)
2D	*D*	*d*
0 %	< 10 %	< 10 %

Sand or *fine aggregate* is the aggregate, or fraction of it, that passes through a 4mm sieve (sieve 4 UNE EN 933-2:96); *gravel* or *coarse aggregate*, that which is retained by this same sieve , and *total aggregate* (or simply *aggregate* when there is no possibility of confusion), that which, by itself or in mixture, possesses the proportions of gravel and sand that are suitable for producing the concrete that is necessary for a particular situation.

The maximum upper size of a coarse aggregate shall be less than the following sizes:

a) 0.8 of the horizontal distance between sheaths or reinforcement bars that do not form a group, or between the edge of a member and a sheath or bar which forms an angle greater than 45° with the direction of placing concrete.
b) 1.25 of the distance between the edge of a member and a sheath or bar which forms an angle not exceeding 45° with the direction of pouring.
c) 0.25 of the smallest dimension of the member, except in the following cases:

    - Upper face of floor slabs, where the maximum upper aggregate size shall be less than 0.4 times the smallest thickness.
    - Very carefully executed pieces (such as those precast in factory) and elements where the wall effect of the formwork is reduced (slabs with formwork on one side only), in which case it shall be less than 0.33 times the smallest thickness.

COMMENTS

The aggregate for a determined application may consist, at the most, of one or more grading fractions, each defined by its designation d/D . When the D/d ratio is equal to or less than 2, it may be considered that the aggregate consists of a single grading fraction.

When concrete is to pass between several layers of reinforcement, it is recommended to use a smaller aggregate size than corresponding to limits a) or b), if these are a determining factor.

28.3 Requirements and tests

In addition to the provisions of 28.1, aggregates should meet the requirements set out below:

28.3.1 Physical-chemical requirements

The amount of harmful substances that may be present in aggregates shall not exceed the limits given in Table 28.3.1.

Table 28.3.1 Limitations for harmful substances

<table>
<tr><th colspan="2" rowspan="2">HARMFUL SUBSTANCES</th><th colspan="2">Maximum amount in % of the total sample mass</th></tr>
<tr><th>fine aggregate</th><th>Coarse aggregate</th></tr>
<tr><td colspan="2">Clay lumps
determined in accordance with UNE 7133:58</td><td>1.00</td><td>0.25</td></tr>
<tr><td colspan="2">Soft particles,
determined in accordance with UNE 7134:58</td><td>–</td><td>5.00</td></tr>
<tr><td colspan="2">material retained by the 0.063 UNE EN 933-2:96 sieve and which floats in a liquid having a density (specific gravity) of 2.
determined in accordance with UNE 7244:71</td><td>0.50</td><td>1.00</td></tr>
<tr><td colspan="2">Total sulphur compounds expressed in $SO^{=}_3$ and referred to the dry aggregate,
determined in accordance with
UNE EN 1744-1:99</td><td>1.00</td><td>1.00</td></tr>
<tr><td colspan="2">Acid-soluble sulphates as $SO^{=}_3$ and referred to the dry aggregate,
determined in accordance with UNE EN 1744-1:99</td><td>0.80</td><td>0.80</td></tr>
<tr><td rowspan="2">Chlorides as Cl^- and referred to the dry aggregate, determined in accordance with UNE EN 1744-1:99</td><td>reinforced or mass concrete that contains reinforcement to reduce cracking</td><td>0.05</td><td>0.05</td></tr>
<tr><td>Prestressed concrete</td><td>0.03</td><td>0.03</td></tr>
</table>

The provisions of 30.1 shall be taken into account with regards to the chloride ion content.

Fine aggregates that contain a proportion of organic material and which produce a darker colour than the standard when tested in accordance with UNE 7082:54 shall not be used.

Fine aggregates shall not be used when their sand equivalent (EAV) as determined “at sight” (UNE 83131:90) is less than:

a) 75, for structures subject to general exposure classes I, IIa or IIb and not subject to any specific exposure class. See tables 8.2.2 and 8.2.3.a.
b) 80, in all other cases.

However, sands produced by the crushing of limestones, that are taken to be carbonate sedimentary rocks containing at least 50% calcite, which do not meet the sand equivalent specification, may be accepted as valid provided that the methylene blue value (UNE 83190:90) is equal to, or less than 0.60 grams of blue per 100 grams of fines for works subject to general exposure classes I, IIa, or IIb and not subject to any specific exposure class, or equal to, or less than 0.30 grams of blue per 100 grams of fines in all other cases.

That indicated in the previous paragraph, with regards to crushed limestone aggregate, may also be applied to aggregates produced by the crushing of dolomite rocks, provided that they show no potential alkali-carbonate reactivity as determined by petrographic examination and the test described in UNE 146507:99 EX Part 2 (chemical method).

Aggregates shall not manifest any potential reactivity with alkalis in the concrete (from cement or other constituents). In order to verify this, a petrographic study should be performed first, which will provide information on the type of reactivity, if any, that might be present.

If the petrographic study of the aggregate suggests the possibility of alkali-silica or alkali-silicate reactivity, the test described in UNE 146507:98 EX Part 1 (chemical method) or the test described in UNE 146508:99 EX (accelerated method on test mortar bars (or specimens)) shall be carried out.

If the petrographic study of the aggregate suggests that there is a possibility of alkali-carbonate reactivity, the test described in UNE 146507:99 EX Part 2 (chemical method) shall be carried out.

COMMENTS

The presence of total sulphur compounds and acid-soluble sulphates in percentages exceeding the limits of the article show the potential instability of the aggregate and, consequently, the danger of its use in the production of concrete because of its ability to affect its durability.

The article limits the maximum chloride content in aggregates, in order to reduce reinforcement corrosion. This limit is stricter for prestressed concrete. In the case of mass concrete, the article does not require any limit. Although it is recommended to limit, both the fine and the coarse aggregate, the chloride content, as Cl^-, at 0.15 percent by mass when it is necessary to prevent the appearance of efflorescence on the surface.

With regards to the prescribed tests, see the general ideas previously explained in the comments to Section 28.1.

The presence of clay fines in the sand could have an adverse affect on both the concrete strength and its durability, which are intended to be prevented with the limits included in the Article (sand equivalent valueand methylene blue test).

In those civil works with special responsibility, where the aggregates are found to posses potential reactivity, it is recommended that long-term tests are performed on concrete specimens in accordance with UNE 146509:99 EX, in addition to those mentioned in the article.

Those works located in environments that are especially favourable to the alkali-aggregate reaction (high moisture and temperature, high alkaline content, etc.), together with those cases where there is no experience about the behaviour of the aggregate, it is recommended that the results be confirmed by employing more than one test method.

In order to evaluate the alkali-silica reactivity (or alkali-silicate) in silica aggregates, there is also the test as indicated in UNE 146507:99 EX, by which the aggregate is considered to be potentially reactive if:

- For $R \geq 70$, the SiO_2 concentration is $>R$
- for $R<70$, theSiO_2 concentration is $>35+0,5R$

This test is not suitable for those aggregates that only react slowly.

For the study of the potential reactivity of calcareous aggregates, there is also the test for stability in an alkaline medium in accordance with UNE 146508:99 EX, by which the aggregate is considered not to be potentially reactive if an expansion of less than 0.05% is obtained in 90-day tests.

It should be taken into consideration that, due to questions of execution and certain technical limitations, qualified specialists should be employed for the carrying out and interpretation of the reactivity tests in accordance with UNE 146507:99 EX and UNE 146508:99 EX .

28.3.2 Physical-mechanical requirements

The following limitations shall be met.

- sand friability (SF) determined in accordance with UNE EN 1097-1:97 (micro-Deval test) ≤ 40

- Resistance to wear of the gravel determined in accordance with UNE EN 1097-2:98 (Los Angeles test) ≤ 40

- Water absorption of the aggregates determined in accordance with UNE 83133:90 and UNE 83134:90 ≤ 5%

The maximum mass loss of aggregates subjected to five treatment cycles with sodium or magnesium sulphate solutions (test method UNE EN 13672-99) shall be no greater than that given in Table 28.3.2.

This test, the main aim of which is to determine the freeze-thaw-resistance of the aggregate, shall only be performed when so indicated in the Project Specification.

Table 28.30.2

Aggregates	Mass loss with magnesium sulphate
Fine	15%
Coarse	18%

28.3.3 Aggregate grading and shape

The amount of fines passing 0.063 UNE-EN 933-2:96 sieve, expressed as a percentage of the total sample mass, shall not exceed the values given in Table 28.3.3.a.

The requirements given in this section with regards to crushed limestone aggregate may also be applied to aggregates produced by the crushing of dolomite rocks, provided that they show no potential reactivity with the alkali from cement as determined by petrographic examination and the test described in UNE 146507-2:99 EX (alkali-carbonate reactivity determination).

The grading curve for fine aggregate shall fall inside the grading limits as defined in Table 28.3.3.b. Those sands that do not meet the limits established by the grading limits may be employed in concrete if it can be experimentally proven that the relevant properties of concretes produced with them are at least, equal to those of concretes produced with the same constituents, but replacing the sand by another one that falls within the grading limits.

These defined grading limits are shown in Figure 28.3.3. The shape of coarse aggregate shall be expressed by its shape coefficient or by its flakiness index; it must meet the prescribed values for either of the two, as indicated below.

The shape coefficient for coarse aggregate, determined by the test method indicated in UNE 7238:71, shall not be less than 0.20. The shape coefficient α of an aggregate is obtained from a set of n representative particles of that aggregate by means of the expression

$$\alpha = \frac{V_1 + V_2 + ... + V_n}{\frac{\pi}{6}(d_1^3 + d_2^3 + ... + d_n^3)}$$

where:

α	Shape Coefficient
V_i	The volume of each particle
d_i	The largest dimension of each particle, i.e. the distance between the two parallel planes tangential to this particle that are the farthest apart of all possible pairs of such planes.

Figure 28.3.3.a Grading limits for fine aggregate

AGGREGATE	MAXIMUM PERCENTAGE passing 0.063 mm sieve	AGGREGATE TYPES
Coarse	1%	- Round aggregates - Crushed non-limestone aggregates
	2%	- Crushed limestone aggregates
Fine	6%	- Round aggregates - Crushed non-limestone aggregates, for works subject to the general exposure classes IIIa, IIIb, IIIc and IV or any other specific exposure class.
	10%	- Crushed limestone aggregates, for works subject to the general exposure classes IIIa, IIIb, IIIc and IV or any other specific exposure class. - Crushed non-limestone aggregates, for works subject to the general exposure classes I, IIa, or IIb and not subject to any other specific exposure class (1).
	15%	- Crushed limestone aggregates, for works subject to the general exposure classes I, IIa, or IIb and not subject to any other specific exposure class (1).

(1) See tables 8.2.2 and 8.2.3.a.

Table 28.3.3.b Grading limits for fine aggregate

Limits	Cumulative percentage retained in the sieves, by mass						
	4 mm	2 mm	1mm	0.5 mm	0.25 mm	0.125 mm	0.063 mm
Upper	0	4	16	40	70	82	(1)
Lower	20	38	60	82	94	100	100

(1) This is the corresponding value in accordance with Table 28.3.3.a:

- 94% for: - Round aggregates.
  - Crushed non-limestone aggregates, for works subject to the general exposure classes IIIa, IIIb, IIIc and IV or those subject to any other specific exposure class.

-90% for: - Crushed limestone aggregates, for works subject to the general exposure classes IIIa, IIIb, IIIc and IV or those subject to any other specific exposure class.
Non-limestone aggregates for works subject to general exposure classes I, IIa or IIb and not subject to any specific exposure class.

-85% for: Limestone aggregates for works subject to general exposure classes I, IIa or IIb and not subject to any specific exposure class.

The flakiness index for coarse aggregate, in accordance with UNE EN 933-3:97, shall be less than 35. The flakiness index for an aggregate is the percentage by mass of aggregate that is considered to be flakes according to the indicated test method.

If an aggregate do not satisfy both limitations, then its use shall depend on initial testing.

COMMENTS

It is important that the aggregate grading remains constant during the works, since any variation could force adjustments in the concrete composition due to the effect on the cement and water contents.

The use of aggregates with unsuitable shape will make it impossible to obtain good strength, and in all cases will require excessive cement contents. For this reason, in order to avoid an excessive presence of laminar and aciculine aggregates, a limit is placed on the shape coefficient or on the flake index. The established limit values are not very demanding, so that only those aggregates with a large amount of unsuitable particles would be outside their range, consequently requiring initial testing as described for this case. Such testing consists in producing concrete specimens, in order to verify if the cement content required for this type of aggregate to meet the concrete specifications is acceptable or not.

28.4 Supply

Before the supply begins, the customer may require the supplier to provide a satisfactory demonstration that the aggregates to be supplied meet the requirements set out in 28.3.

The supplier shall notify the customer of any change in production that might affect the validity of the information provided.

Each delivery of aggregate shall be accompanied by a delivery ticket, containing the following information, and which shall be available to the Project Management at all times.

- Supplier name.
- serial number of ticket.
- Quarry name.
- Delivery date.
- Customer name.
- Aggregate type.
- Amount of aggregate supplied.
- Aggregate designation (d/D).
- Identification of supply location.

28.5 Storage

Aggregates should be stored so that they are protected from any possible contamination from the environment, especially from the ground; the different grading fractions should not be mixed.

All necessary precautions should also be taken to prevent segregation during both storage and transport.

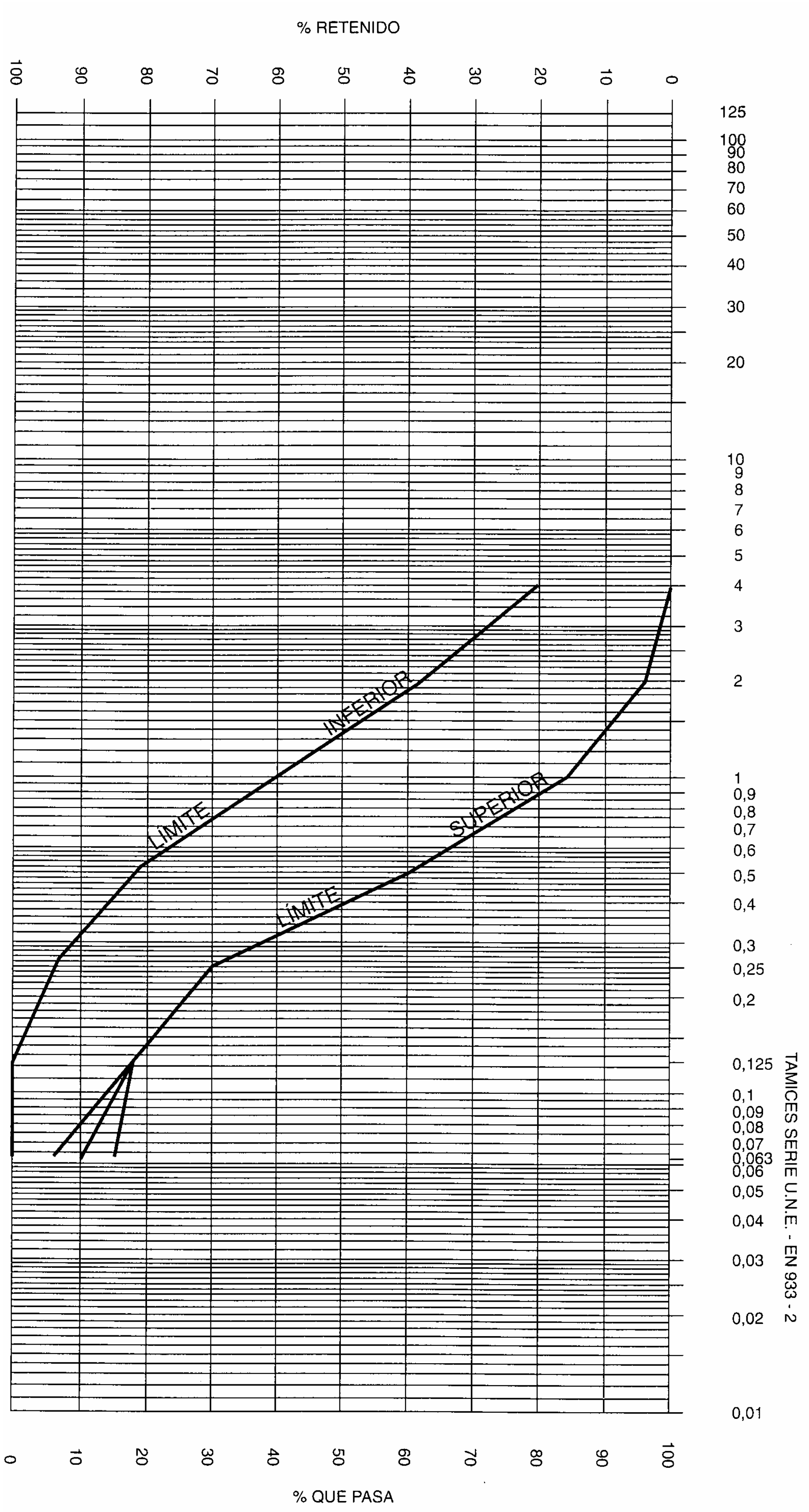

Figure 28.3.3. Grading limits for fine aggregate

COMMENTS

In order to avoid the use of aggregates that are excessively hot during the summer months or saturated with moisture during those of winter, it is recommended that they be stored inside, in suitable protected and insulated enclosures. If, on the contrary, this is not possible, then suitable precautions shall be taken to avoid any harm that might be caused by the high temperatures or excessive moisture levels.

Article 29 Other concrete constituents

Other concrete constituents that might be used are admixtures and additions, provided it can be demonstrated through suitable tests that if the substance is added in the proportions and under the conditions proposed, then it will produce the desired effect without excessively affecting the remaining characteristics of the concrete or representing a danger to the durability of the concrete or corrosion of the reinforcement.

With respect to the chloride ion content, the provisions of 30.1 shall be taken into account.

Additions shall not be used without the knowledge of the customer, together with the specific permission of the Project Manager. The use of admixtures shall comply with the provisions of 69.2.8.

29.1 Admixtures

Admixtures are substances or products which, when incorporated into the concrete before mixing (or during mixing or during a supplementary mixing) in a proportion no greater than 5% of the mass of cement, produce a desired change in certain of its characteristics, usual properties or performance, in either the fresh or hardened state.

Calcium chloride and chloride, sulphide or sulphite based admixtures or other chemical components that may cause or encourage reinforcement corrosion, shall not be added to reinforcement or prestressed concrete .

In prestressed elements, where the reinforcement is anchored exclusively through bonding, air-entraining agents shall not be used.

The source documents shall show the name of the admixture in accordance with UNE EN 934-2:98, together with a certificate of guarantee from the producer that the characteristics and especially the performance of the admixture, when added in the right proportions and under the right conditions, are such that they will produce the main desired function without excessively affecting the remaining characteristics of the concrete or representing any danger to the reinforcement.

Admixtures shall be transported and stored in such a manner as to avoid contamination and prevent any change in their properties by physical or chemical factors (frost, high temperature, etc.). The producer shall supply the admixture correctly labelled, in accordance with UNE 83275:89 EX.

Any admixtures that change the rheological performance of concrete shall comply with UNE EN 934-2:98. Admixtures that affect the setting time shall comply with UNE EN 934-2:98.

COMMENTS

The performance of admixtures may vary with the particular conditions of each type of works, cement type, cement content,aggregate nature etc. This is why it is essential to perform initial testing in each and every case (see (81.4.2), and very especially when employing cements other than CEM I.

The prohibition on the use of air-entraining agents for the case given in the article (prestressed elements with reinforcements that are anchored exclusively by bonding) is based on the fact that these substance might adversely affect the bond between the concrete and the reinforcement.

With regards to plasticizers, it should be taken into account that these products improve the place of concrete and allow a reduction in the water/cement ratio, with the consequent benefit in its resistance. However, at the same time, this could delay the setting and hardening process of the concrete. therefore, when plasticizer or water-reduzing admixtures are used which have the secondary effect of delaying the setting and hardening of the concrete, it will be necessary to increase the period to remove the moulds from the pieces, and additionally, in the case of prestressed concrete, the time required before applying the prestress force to the concrete.

The use of calcium chloride as an accelerator is usually beneficial with mass concrete when used in the correct proportions (in the order of 1.5% to 2% of the mass of cement). However, this cannot be said for the case of reinforced concrete, where its presence sometimes causes, but always encourages, corrosion phenomena in the reinforcement. For this reason, its use is forbidden in reinforced or prestressed concrete.

The water content of liquid admixtures should be taken into account in concrete composition and in the calculation of its water/cement ratio. Additionally, concrete production should be carried out with suitable quality control over the amount of admixture added (since a significant excess of admixture may have a detrimental effect on concrete).

29.2 Additions

Additions are finely divided inorganic, pozzolanic or latent hydraulic materials used in concrete in order to improve certain properties or to achieve special characteristics. This Instruction only deals with the use of two types of additions: fly ash and silica fume.

With the one exception of silica fume, the use of any type of addition, in particular fly ash, as a constituent of prestressed concrete is forbidden.

Fly ash is the solid residue collected by electrostatic or mechanical precipitation of dust-like particle from the flue gases of thermal generating station furnaces fired with pulverized coal.

Silica fume is a by-product produced by the reduction of high-quality quartz with carbon in electric arc furnaces for the production of silicon metal and ferro-silicon alloys.

Fly ash and silica fume may be used as a concrete addition only when cement type CEM I is used.

In building structures, the maximum amount of fly ash that may be added shall not exceed 35% of the mass of the cement, whereas the maximum amount of silica fume added shall not exceed 10% of the mass of the cement. The minimum amount of cement is specified in 37.3.2.

COMMENTS

Due to the extreme fineness of silica fume, together with its high content of silicon oxide, and also due to its exceptional activity, its main application is the production of high-strength concretes. In addition, it confers high consistency and mechanical strength to the concrete, it may also cause a reduction in the pH of the concrete, which should be taken into account in exposure conditions that induce significant carbonation of the concrete.

Since both fly ash and silica fume are by-products, special care should be taken at the concrete plant to guarantee regularity through acceptance tests of the various supplies in order to verify that any possible variations in its composition do not adversely affect the concrete produced with them.

29.2.1 Fly ash requirements and tests

Fly ash shall not contain any harmful ingredients in such quantities that may be detrimental to the durability of the concrete or cause corrosion of the reinforcement. They shall also comply with the following requirements in accordance with UNE EN 450:95.

- Sulfuric anhydride (SO_3), in accordance with UNE EN 196-2:96	≤ 3.0%
- Chloride (Cl^-), in accordance with UNE 80217:91	≤ 0.10%
- Free calcium oxide, in accordance with UNE EN 451-1:95	≤ 1%
- Loss on ignition, in accordance with UNE EN 196-2:96	≤ 5.0%
- Fineness, in accordance with UNE EN 451-2:95	
Amount retained by a 45 µm sieve	≤ 40%
Activity Index, in accordance with UNE EN 196-1:96	
at 28 days	> 75%
at 90 days	> 85%
- Soundness (Expansion with the needle method),	
in accordance with UNE EN 196-3:96	< 10 mm

Soundness specification shall only be taken into account if the free calcium oxide content is greater than 1%, but less than 2.5%.

Any analysis and initial test results shall be made available to the Project Management.

COMMENTS

Fly ash with a high calcium oxide content may lead to expansion problems in the concrete, and it is therefore recommended that extreme precautions are taken and frequent checks made on the fineness of the fly ash and soundness by the needle method.

The article requirements are similar to those of UNE EN 450:95. In addition, guidelines are given in UNE 83414:90 for fly ash use as addition on concretes containing cement type CEM I.

29.2.2 Silica fume requirements and tests

Silica fume shall not contain any harmful ingredients in such quantities that may be detrimental to the durability of the concrete or cause corrosion to the reinforcement. In addition, it shall comply with the following requirements:

- Silicon dioxide (SiO_2), in accordance with UNE EN 196-2:96	≥ 85%
- Chloride (Cl^-), in accordance with UNE 80217:91	< 0.10%
- Loss on ignition, in accordance with UNE EN 196-2:96	< 5%
- Activity index, in accordance with UNE EN 196-1:96	> 100%

Any analysis and initial test results shall be made available to the Project Management.

COMMENTS

UNE 83460:94 EX provides guidelines for the use of silica fume as a concrete addition..

29.2.3 Supply and storage

For fly ash or silica fume supplied in bulk, the equipment used shall be similar to that used for cement. In order to provide protection against moisture and contamination they should be stored in impermeable containers and silos, which should be clearly identified to prevent possible errors in dosing.

The supplier shall identify the addition and provide documentary guarantee of it complying with the specifications given in 29.2.1 or 29.2.2, according to whether the addition is fly ash or silica fume.

Article 30 Concrete

30.1 Composition

Concrete composition , selected for the construction of structures or structural elements , shall be previously study in order to guarantee that the mechanical, rheological and durability properties of the concrete meet the project requirements. Any such studies shall take into account the actual conditions of the works as far as this is possible (diameters, surface characteristics and distribution of reinforcement, compaction method, dimensions of the members etc.).

The concrete constituents shall comply with the requirements given in Articles 26, 27, 28 and 29. In addition, the total chloride ion content of all the combined constituents shall not exceed the following limits (see 37.4):

- Prestressed concrete	0.2% of the mass of the cement
- Reinforced concrete or mass concrete containing reinforcement to reduce cracking	0.4% of the mass of the cement

COMMENTS

Although they are valid for the majority of environmental conditions that might occur, the established limits for the ion chloride content should be used with prudence. It should be considered that, although under certain conditions (such as, permanently very low or very high relative humidity) they could be somewhat conservative, in others (intermediate relative humidity, and, above all, non-seasonal hygrometric conditions, together with carbonated concrete) it may be necessary to reduce these limits.

30.2 Quality conditions

The quality conditions or properties required of the concrete should be specified in the Project Specification, where the following items should always be indicated: compressive strength, consistency, maximum aggregate size, type of environment in which it will be used, and where necessary, any specifications of admixtures and additions, concrete tensile strength, absorption, specific gravity, compaction, wear resistance, permeability and external appearance etc.

These conditions should be met by all the individual product units that make up the whole, where a product unit means the amount of concrete produced at any one time. Usually, the concept of a product unit is associated with one batch, but in certain cases and for the purposes of control it may instead refer to the amount of concrete produced in a particular period of time and essentially under the same conditions. In this Instruction the word “batch” is used as an equivalent for product unit.

For the purposes of this Instruction, any measurable property of quality for a batch shall be expressed by the average value of a number of determinations (at least two) of the quality property itself, performed on parts or portions of the batch.

COMMENTS

It should be taken into account that compressive strength is not a sufficient indication of all other properties of concrete. For this reason it is not enough to specify a certain value for this strength in order to have guarantees of the existence of sufficient levels of other properties that might be significant in any given specific situation.

There are situations where it is necessary to specifically require a minimum in relation to a specific concrete quality: wear resistance in a pavement, freezing-thawing resistance at a mountain works, the impermeability of a water tank etc. However, it is not possible to provide specific indications of this type in an Instruction. For this reason the article refers to the Project Specification for each works, which should specify the standardised test method that shall be employed for the verification of the corresponding quality, together with the acceptable limit figures for the results, in each case and in accordance with that established in 4.4.

All the qualities required of the concrete shall be clearly specified in the Project Specification by means of suitable acceptance limits, which, depending on the situation, will be lower, upper or intermediate limits. Any batch that does not meet one or more specifications shall be treated as defective.

In order for the specifications contained in the Project Specification to be complete, it is necessary to associate each required condition or quality, a percentage of product units or defective batches that may be accepted as a maximum in the total under consideration. The fixing of this percentage should be established after a study of the situation, weighing up all circumstances at the works, especially any repercussions on the costs, reliability and safety.

For the compressive strength, this Instruction has adopted a lower characteristic value so that the defective batch percentage, with less than the specified strength, is 5%. For the current level of concrete technology, 5% defective batches are perfectly acceptable for most quality characteristics.

30.3 Mechanical properties

The mechanical properties of the concretes used in structures shall comply with the conditions set out in Article 39.

For the purposes of this Instruction, the compressive strength of concrete refers to the strength of the product unit or batch, and is obtained from the results of at least two tests carried out on at 28 days on cylinders (15 cm in diameter by 30 cm in length), made from the batch and stored in accordance with UNE 83301:91, faced according to UNE 83303:84 and tested in compression in accordance with UNE 83304:84.

In certain works where the concrete will not be subject to any stress for the first three months after casting, the compressive strength may refer to 90-day concrete.

For certain works or parts of the same, the Project Specification may require the determination of the tensile strength or flexural strength of the concrete through the application of standardised test methods.

For the purposes of this Instruction, rapid hardening concretes are considered to be those made with cement of strength classes 42.5R, 52.5 or 52.5R provided that their water/cement ratio is less than, or equal to, 0.60, those made with cements of strength classes 32.5R or 42.5 provided their water/cement ratio is less than, or equal to, 0.50, or those in which a setting accelerator is used. The remaining types are considered as being normal-hardening concretes.

COMMENTS

The given definition for concrete compressive strength is no more than a convention that allows a value in relation to the physical concept of material strength to be associated with each concrete product unit or batch, which although it is different, is sufficiently representative for the practical purpose of this Instruction.

The previous statement accepts the homogeneity of the concrete of each batch, which implies that any discrepancies in the results obtained from working with parts of the batch are attributed to errors involved in the test methods (sampling moment making and curing specimens, transport etc). Whenever the difference between the results of the same product unit exceed certain limits, it would seem reasonable not to confer any absolute representative nature without prior verification of the process being employed.

In order to guarantee the stated homogeneity, the relative range of a group of three specimens (the difference between the largest and smallest results, divided by the average value of the three), taken from the same batch, may not exceed 20%. The relative range may not exceed 13% for the case of two test cylinders.

UNE 83306:85 specifies the means and procedures that shall be employed when determining the indirect tensile strength, (Brazilian test) on cylinders. The determination of the flexural strength $f_{ct,fl}$ has been standardised in UNE 83305:86.

The tensile strength, f_{ct}, may be obtained from the previous values using the following expressions:

$$f_{ct} = 0,90\, f_{ci}$$

$$f_{ct,fl} = f_{ct} \frac{1 + 1,5\left(\frac{h}{100}\right)^{0,7}}{1,5\left(\frac{h}{100}\right)^{0,7}}$$

where:

h Overall depth of member, in mm.

30.4 Conversion factors

Should the only results that are available be those for tests conducted on specimens other than 15 x 30 cm cylinders or performed at ages other than 28 days, it will be necessary to use conversion factors to obtain the values corresponding to the standard conditions. These conversion factors vary from one type of concrete to another, which means that a general rule cannot be established.

This means therefore, that any value obtained through the use of conversion factors will have no validity other than for information purposes.

COMMENTS

For a given concrete, only comparative testing, periodically repeated throughout the works period, enables the determination of conversion factors that are applicable to the results of tests performed on specimens different to the cylinders 15 x 30 cm , in order to obtain values comparable to the previous ones.

When suitable tests are not available, and for orientation purposes, Table 30.4.a, provides an approximate indication of the conversion factors applicable to each case.

When there is only data available for 28-day tests, and there is no corresponding experimental data for the concrete, it is possible to accept the values of Tables 30.4.c and 30.4.c as a guideline for the relationship between the strength at *j* days and that of 28 days.

Table 30.4.a Compression tests different types of specimens at the same age

Type of specimen	Dimensions (cm)	Conversion factor for the 15 x 30 cm test cylinder	
		Variance limits	Average values
Cylinder	15 x 30	----	1.00
	10 x 20	0.94 to 1.00	0.97
	25 x 50	1.00 to 1.10	1.05
Cube	10	0.70 to 0.90	0.80
	15	0.70 to 0.90	0.80
	20	0.75 to 0.90	0.83
	30	0.80 to 1.00	0.90
Prism	15 x 15 x 45	0.90 to 1.20	1.05
	20 x 20 x 60	0.90 to 1.20	1.05

Table 30.4.b Compressive strength on specimens of the same type

Concrete age, in days	3	7	28	90	360
Normal hardening concretes (1)	0.40	0.65	1.00	1.20	1.35
Rapid hardening concretes (1)	0.55	0.75	1.00	1.15	1.20

(1) See the definition for rapid or normal hardening concrete in 30.3.

Table 30.4.c Tensile strength on specimens of the same type

Concrete age, in days	3	7	28	90	360
Normal hardening concretes (1)	0.40	0.70	1.00	1.05	1.10

(1) See the definition for rapid or normal hardening concrete in 30.3.

30.5 Minimum strength value

The project strength (characteristic strength) f_{ck} (see 39.1) shall not be less than 20 N/mm^2 in mass concretes, or 25 N/mm^2 in reinforced or prestressed concretes.

However, the provisions of the first paragraph, when the design establishes a reduced level of control for mass or reinforced concrete for engineering works of lesser importance, in housing structures of one or two storeys with spans of less than 6.00 metres, or in elements that work in flexion in housing structures of up to four storeys with spans of less than 6.00 metres, a value of no greater than 10 N/mm^2 should be adopted for the design compressive strength f_{cd} (see 39.4).

In these cases of reduced control level for the concrete, the minimum amount of cement in the concrete mix shall comply with the requirements of Table 37.3.2.a.

COMMENTS

The use of concretes with a strength of less than 20 N/mm² , which are not dealt with in this Instruction, shall be limited exclusively to non-structural works units (for example, curbs and clean-up concrete etc).

The article explicitly excludes reinforcement concretes with a project strength of less than 25 N/mm². In the particular case where the project establishes a reduced control level for the concrete (a control level, which, within the context of this Instruction should be considered as being clearly residual), the project strength shall comply with the previous specification, although the design compressive strength, f_{cd}, should not exceed 10 N/mm².

30.6 Concrete workability

The workability of the concrete shall be such that, with the proposed place and compaction methods, it surrounds the reinforcement without any gaps and completely fills the formwork without leaving any blow holes or air pockets. The workability of concrete shall be evaluated by determining its consistency, in accordance with UNE 83313:90.

with the test method described in the UNE 83313:90,determine the consistency of concrete measuring its slump in the Abrams cone, and is expressed as a whole number of centimetres.

It is generally recommended that the slump of concrete for buildings should not be no less than 6 centimetres.

The various consistencies and limit values for the corresponding slump in the Abrams cone are as follows:

Type of Consistency	Slump in cm
Dry	0 - 2
Plastic	3 - 5
Soft	6 - 9
Fluid	10 - 15

The upper limit of slump set for fluid consistency (15 cm) may be exceeded when use superplasticizers.

The consistency of concrete to be used shall be specified in the Project Specification. It may be specified by type or by target value, *A*, in cm, with the tolerances as indicated in Table 30.6.

Table 30.6 Tolerances for concrete consistency

Consistency as defined by type		
Consistency type	Tolerance in cm	Resultant interval
Dry Plastic Soft Fluid	0 ±1 ±1 ±2	0 - 2 2 - 6 5 - 10 8 - 17
Consistency as defined by slump		
Slump in cm	Tolerance in cm	Resultant interval
Between 0 - 2 Between 3 - 7 Between 8 - 12	±1 ±2 ±3	A ±1 A ±2 A ±3

COMMENTS

With respect to the determination of consistency, the prescribed procedure is simple and very easy to perform. However, in the case of dry consistency concretes, the slump test is less suitable, and the Vebe test (UNE 83314:90) may be employed in its place.

The articles recommends a slump of no less than 6 cm for building works. However, in the case of uncovered concrete, it may be advisable to employ plastic consistency concretes, which shall be properly placed and compacted.

In the case of concretes produced with superplasticizers, the value of the water/cement ratio is of greater priority than the consistency, and shall meet the durability requirements given in the Instruction (37.3.2). The article therefore indicates that in these cases, the upper slump value established for the fluid consistency is no longer valid.

Article 31 Reinforcement

31.1 General

- Ribbed bars.
- Wire fabrics.
- Lattice girders.

The nominal diameters of the ribbed bars shall conform to the following series:

6 - 8 - 10 - 12 - 14 - 16 - 20 - 25 - 32 and 40 mm.

The nominal diameters of the ribbed wires used in wire fabrics shall conform to the following series:

5 – 5.5 - 6 – 6.5 - 7 – 7.5 - 8 – 8.5 - 9 – 9.5 - 10 – 10.5 - 11 – 11.5 - 12 and 14 mm.

In addition to fabrics made of wires of the diameters given above, wire fabrics made of ribbed wires of 4 or 4.5 mm diameter may be used for distributing and controlling of surface cracking. These fabrics shall not be taken into account during Ultimate Limit State verifications.

However, wire fabrics consisting of ribbed wires with a diameter of 4 or 4.5 mm may be employed in Ultimate Limit State verifications until the 31st of December 2000.

The nominal diameters of plain or ribbed wires used in lattice girders shall conform to the following series:

5 - 6 - 7 - 8 - 9 - 10 and 12 mm.

Exclusively in the case of one-way concrete floor slabs in which lattice girders are used, the diagonals may be made of 4 and 4.5 mm diameter wires, in addition to wires of the diameters given above.

The bars and wires shall not present any surface flaws, cracks or air holes.

The equivalent section shall never be less than 95.5 per cent of the nominal section For the purposes of this Instruction, the yield stress of steel, f_y, shall be taken as being the stress that produces a residual strain of 0.2%.

Ribbed wires may be used as components of wire fabrics and lattice girders (in the latter case, plain wires also may be used as diagonals). In the specific case of reinforced or prestressed concrete one-way floor slabs, the provisions of the relevant Instruction shall be followed. Any other use of plain or ribbed wires as reinforcement, apart from those mentioned above (whether longitudinal or transverse), is expressly forbidden.

COMMENTS

The nominal diameter of a ribbed bar is the number that defines the circle with respect to which the tolerances are established. The area of this circle is the nominal section of the bar.

The equivalent section of a ribbed bar, in square centimetres, is understood as being its weight quotient, in Newtons, by 0.077 (7.85 if its weight is expressed in grams) times its length in centimetres. The diameter of the circle with an area equal to the equivalent section is known as the equivalent diameter.

The determination of the equivalent section of a bar shall be performed after it has been carefully cleaned in order to eliminate any possible rolling flakes and oxide that is not firmly adhering.

In those steels that present clearly defined flow range, the yield stress coincides with the apparent value for the corresponding stress at that range. When the steel does not present this range or it appears ill-defined, it is then necessary to recur to the conventional value described in the article. In all cases, the yield stress may be designate as f_y.

Ribbed wires are manufactured using cold forming processes, and with the current production process, there are usually three rows of longitudinal ribs, which enables them to be distinguished from ribbed bars, which are always manufactured with hot rolling techniques that may or may not be followed by a cold deformation process.

In surface elements (slabs, shells, etc.), wire fabrics are usually especially suitable, although these may also be highly indicated in other types of elements, such as columns and other linear elements. With respect to lattice girders, its main use is in floor slabs.

In general, it is recommended to use on site the minimum number of bar sizes, and that the difference among them is as large as possible.

The diameter set that makes up the series established for the bars has the advantage that each size may be differentiated from the others by the naked eye. In addition (with the exception of the 14-mm diameter), the section of each size is approximately equivalent to the sum of the two preceding sections, which facilitates the various combinations in use. Moreover, the use of this same series is currently recommended throughout Europe.

In the case of fabrics, the use of the 5 - 6 - 7 - 8 - 9 - 10 and 12 mm series is recommended for the usual situations (standard fabrics), leaving the others for special cases where these diameters are required by the reinforcement requirements (special fabrics).

The properties of fabrics produced with 4 or 4.5 ribbed wires (in accordance with UNE 36099:96), make it necessary to restrict use to the distribution and control of surface cracking in elements, such as, floors, pavements, distribution slabs, pile covering , skin reinforcement, etc. Therefore, this type of reinforcement shall not be taken into account as resistant during the project when compared to the ultimate limit states.

It is advisable that the producers make use of data sheets containing the properties of the steel produced, and which should consist of at least the following:

- Commercial name
- Producer
- Identification marks
- Nominal diameter
- Types of steel
- Technical supply conditions

together with the following guaranteed properties:

- Equivalent section or mass per metre
- Ribbing geometry
- Minimum mechanical properties
- Bonding characteristics
- Weldability

as well as guidelines for its use.

31.2 Ribbed bars

For the purposes of this Instruction, ribbed bars are those that meet the technical requirements established in UNE 36068:94, including:

- In the flexural bond test described in UNE 36740:98 "Determination of bonding of steel bars and wires for reinforced concrete, Beam test", they should present a mean bond stress τ_{bm} and ultimate bond stress τ_{bu} that satisfy the following two conditions simultaneously:

  - Diameters of less than 8 mm:

$$\tau_{bm} \geq 6,88$$
$$\tau_{bu} \geq 11,22$$

  - Diameters from 8 to 32 mm inclusive:

$$\tau_{bm} \geq 7,84 - 0,12\phi$$
$$\tau_{bu} \geq 12,74 - 0,19\phi$$

  - Diameters greater than 32 mm:

$$\tau_{bm} \geq 4,00$$
$$\tau_{bu} \geq 6,66$$

  where τ_{bm} and τ_{bu} are expressed in N/mm² and ∅ in mm.

  The bonding properties are to be specifically certified by one of the authorized bodies mentioned in Article 1 of this Instruction for issuing the Certificate of Compliance with Essential Requirements (CCER). The certificate shall explicitly mention of the permissible limits of variation in the ribbing geometry.

For control purposes, it is sufficient to verify that the steel possesses the specific bonding certificate and to carry out a geometric check to verify that the ridges or ribs of the bars (after straightening, if necessary) are within the limits stated on the certificate.

- The minimum mechanical characteristics as guaranteed by the producer, in accordance with the requirements of Table 31.2.a.

Table 31.2.a
The minimum guaranteed mechanical properties for ribbed bars

Designation	Type of steel	Yield stress f_y in N/mm² not less than (1)	Ultimate tensile stress (Tensile strength) f_s in N/mm² not less than (1)	Elongation to failure in % based on 5 diameters not less than	f_s/f_y ratio in testing not less than (2)
B 400 S	Weldable	400	440	14	1.05
B 500 S	Weldable	500	550	12	1.05

(1) The nominal section shall be used in calculating unit values.
(2) Minimum permissible ratio between the ultimate unit load (tensile strength) and the yield stress obtained during each test.

- Absence of cracking after the reverse bend test (Sub-section 10.3 of UNE 36068:94) on the appropriate mandrels in accordance with Table 31.2.b.

Table 31.2.b
Mandrel diameters

Designation	Bend - reverse bend $\alpha = 90°$ $\beta = 20°$			
	$d \leq 12$	$12 < d \leq 16$	$16 < d \leq 25$	$d > 25$
B 400 S	5 d	6 d	8 d	10 d
B 500 S	6 d	8 d	10 d	12 d

where:

d Nominal bar diameter
α Bend angle
β Reverse bend angle

- The bars shall carry identification marks as established in Section 12 of UNE 36068:94 with regards to the type of steel (ribbing geometry), country of origin (the mark corresponding to Spain is the number 7) and the mark of the producer (in accordance with the code given in Technical Report UNE 36811:88).

Since this Instruction covers only weldable steels, the producer shall indicate the recommended welding procedures and conditions, where necessary.

COMMENTS

The anchorage and lap lengths of the ribbed bars indicated by this Instruction in 66.5 and 66.6. were established on the basis that the steel fulfils the flexural bond test described in UNE 36740:98. For this reason, the article emphasises the need to fulfil this test through the carrying out of specific tests.

The procedure for the measurement of the bonding between the steel and the concrete is always conventional, in the same manner as the definition of the bond stress τ_b. For this motive, this subject is referred to the test method included in UNE 36740:98 , where the stresses τ_{bm} and τ_{bu} are defined, together with the operational procedure.

The specific certification of the bonding properties means that the steel is recognised as complying with the conditions required for bonding. As established in UNE 36740:98, for each producer and type of steel, the tests consist of three series of tests with 25 test bars in each , referring to diameters of 8, 16 and 32 cm. respectively. The test bars are produced from a total of 25 bars each 10 metres long for each diameter.

For the situation of structures in earthquake zones, Annex 12 establishes the requirements of ductility that shall be met and which are clearly more severe than those given in Table 31.2.a. Annex 12 also indicates the specifications for weldable steel with special ductility properties, B 400 SD, which satisfies these requirements.

It is recommended that the producer guarantees a characteristic stress-strain diagram for the steel, up to a strain of 10 per 1,000, based on thorough experimentation.

The mandrel diameters for the bend – reverse bend test in Table 31.2.b are considered as being the maximum. The producer may use smaller mandrels than those specified for each use, provided that the test results are satisfactory. In the case of a negative results, the test should be repeated using the size of mandrel indicated in the table.

It should be remembered that the welding quality of steel is closely linked to the actual procedure employed to weld it. In the case of elements subject to alternate loads, the welds form zones of less resistance to fatigue, so that it is recommended that they are limited to the lowest possible number and located in areas of low stress.

31.3 Wire fabrics

For the purposes of this Instruction, wire fabrics are those which comply with the technical requirements established in UNE 36092:96.

Wire fabric is made with ribbed bars which comply the requirements of 31.2 or ribbed wires which meet the bonding conditions as specified in 31.2, together with the requirements of Table 31.3.

Table 31.3
Guaranteed minimum mechanical properties for wires

Designation	Tensile strength test (1)				Bend - reverse bend test α = 90° (5) β = 20° (6) Mandrel diameter D’
	Yield stress f_y N/mm² (2)	Ultimate tensile stress(Tensile strength) f_S N/mm² (2)	Elongation to failure (%) based on 5 diameters	Ratio f_s/f_y	
B 500 T	500	550	8 (3)	1.03 (4)	8 *d* (7)

(1) Guaranteed minimum characteristics values.

(2) When determining the yield stress and the unit load (tensile strength), the nominal value for the cross-sectional area shall be used to divide the loads.

(3) The following condition should also be met:

$$A\% \geq 20 - 0{,}02\, f_{yi}$$

where:

A Elongation to failure

f_{yi} Yield stress as measured in each case

(4) The following condition shall also be met:

$$\frac{f_{si}}{f_{yi}} \geq 1{,}05 - 0{,}1\left(\frac{f_{yi}}{f_{yk}} - 1\right)$$

where:

f_{yi} Yield stress as measured in each case

f_{si} Unit load (tensile strength) obtained in each test

f_{yk} Guaranteed yield stress

(5) α Bend angle.

(6) β Reverse bend angle.

(7) *d* Nominal wire diameter

Each bundle shall arrive at delivery (site, bar-bending workshop or warehouse) with an identification label conforming with UNE 36092-1:96. The bars or wires that make up wire fabrics shall be marked with identification marks, in accordance with Technical Reports UNE 36811:98 and UNE 36812:96 for ribbed bars and wires respectively, as established in 31.2.

COMMENTS

In the bonding test (UNE 36740:98), since the maximum diameter of the ribbed wires is 14 mm, only two series are distinguished: a fine series (∅ ≤ 8 mm) and a medium series (∅ > 8 mm).

For each producer and type of steel, the tests consist of two series of tests with 25 test bars in each, referring to diameters of 8 and 12 mm cms respectively. The test bars are produced from a total of 25 bars each 10 metres long for each diameter.

The wire fabrics are described, in accordance with UNE 36092:96, as follows:

$$ME\ s_l \times s_t\ A\ \varnothing d_l - d_t\ B\ 500\ X\ l \times b\ UNE\ 36092{:}96$$

where:

ME Product letters.

s_l , s_t Distance between the longitudinal and transverse wires respectively, in centimetres, and joined with the x sign.

A Indication of whether the panel is with or without saving, in accordance with the following code:

-	with standard saving	A
-	with non-standard or special saving	E
-	without bar savings	No symbol

d_l , d_t The diameters of the longitudinal and transverse wires respectively, in millimetres, and preceded by the ∅ symbol. Each diameter d_l or d_t shall be followed by the letter D in double fabrics.

B A letter indicating the type of steel (steel for reinforced concrete), followed by a three-figure number indicating the nominal yield stress for the steel, in N/mm², together with a letter that indicates the class of steel employed (S if steel in accordance with UNE 36068:98 has been used, and T if steel in accordance with UNE 36099:96 was employed).

l Panel length, in metres.

b Panel width, in metres.

Example of a wire fabric designation: designation of a ribbed wire, electrically-welded fabric, with high bonding and 500 N/mm² yield stress, with a 15 cm longitudinal wire axis distance, and 30 cm separation between cross-sectional wires, 10 mm longitudinal wire diameter, and 6.5 mm cross-sectional wire diameter, a 2 m wide and 5 m long panel, with standard saving.

ME 15 x 30 A ∅10 – 6.5 B 500 T 5 x 2 UNE 36092:96

It should be taken into account that the on-site identification of the diameters should be carried out with special care, because if not, identification errors might occur, especially with ribbed wire fabrics since the diameter variation is half a millimetre.

It is recommended that the producer guarantees characteristic stress-strain diagram for the wires, up to a deformation of 10 per 1,000, based on thorough experimentation.

31.4 Lattice girders

For the purposes of this Instruction, lattice girders are those which comply with the technical requirements established in UNE 36739:95 EX

Lattice girder is a three-dimensional structure formed by a system of elements (bars or wires), with points of contact which are automatically welded together electrically.

It consists of an upper longitudinal element, two lower longitudinal elements and two transverse linking elements, forming a cage. All the elements consist of bars or wires, which would be ribbed, in the case of the upper and lower elements, and may be plain or ribbed in the case of the linking elements.

The elements that make up lattice girders shall meet the requirements of 31.2 in the case of ribbed bars, and those of 31.3 in the case of plain or ribbed wires. Ribbed wires shall also meet the bonding conditions specified in 31.2.

The bundles of reinforcement shall arrive at delivery (site, bar-bending workshop or warehouse) with an identification label as specified in UNE 36739:95 EX. The bars or wires that make up lattice girders shall be marked with identification marks in accordance with Technical Reports UNE 36811:88 and UNE 36812:86 for ribbed bars and wires respectively, as established in 31.2.

COMMENTS

Lattice girders are described in the following fashion, in accordance with UNE 36739:95 EX:

a) The designation of the type of lattice girder, consisting of the following symbols:

- The product's distinctive letters AB.
- Total base width (b_1) and total height (h_1), in mm, joined by the *x* sign.
- The lattice pitch (c), in mm, preceded by the / sign.
- The diameter of the upper longitudinal element (d_s), in mm.
- The number of bars or wires and the diameter of the lattice elements (d_c), in mm.
- The L symbol, when the lattice elements are plain wires.
- The number of bars or wires and the diameter of the lower longitudinal elements (d_i), in mm.

b) Designation of the type of steel:

- B 500 T for material in accordance with UNE 36099:96 or UNE 36731:96.
- B 500 S or B 400 S for material in accordance with UNE 36068:94.

c) Reinforcement length (l) in m.

d) With reference to UNE 36739:95 EX.

Designation example for a 12-metre long lattice girder, 9 cm total base width and 17 cm total height, consisting of 6-mm diameter ribbed wire B 500 T for the upper element, two 5-mm diameter plain wire elements B 500 T as linking elements (lattice) with a 20-cm pitch and two 6-mm diameter ribbed wires B 500 T as lower elements.

a) AB 90 x 170/200 ∅6 2 ∅5 L 2∅6
b) B 500 T
c) 12
d) UNE 36739:95 EX.

31.5 Supply

A distinction is made between the supply of certified products and that of non-certified products.

COMMENTS

In the cases of both certified and non-certified products, the Instruction requires that quality control tests be performed on the steel (see Article 90) on acceptance, although test intensity will vary from one case to another.

In general, the straight bar is considered to be the most suitable form of supply. However, other usual forms are accepted in practice, always provided that they comply with the bending diameter limitations described in UNE 36068:94.

31.5.1 Certified products

For steel in possession of a recognised quality mark or a Certificate of Compliance with Essential Requirements (CCER), both as explained in Article 1 of this Instruction. In the case of ribbed bars or ribbed wires it shall also be accompanied by the specific bonding certificate, as well as a certificate of guarantee of the producer indicating the limit values for the various properties mentioned in 31.2, 31.3 and 31.4 in order to justify that the steel complies with the requirements contained in this Instruction.

Whenever requested, the producer shall also provide a copy of the results of the production control tests corresponding to the material delivered.

31.5.2 Non-certified products

In the case of products that do not possess a quality mark or a Certificate of Compliance with Essential Requirements (CCER) as explained above, each delivery shall be accompanied by the results of chemical composition tests, mechanical properties and geometric properties, performed by one of the CCER-issuing bodies mentioned in Article 1 of this Instruction, in order to justify the fact that the steel complies with the requirements laid down in 31.2, 31.3 and 31.4, as applicable. In the case of ribbed bars or ribbed wires, it should also be accompanied by the specific bonding certificate.

31.6 Storage

During both transport and storage, reinforcement shall be suitably protected from rain, ground moisture and any attack of the surrounding environment. Before use reinforcement shall be stored on-site, correctly classified by type, quality, diameter and source.

Before use, and especially after a long storage period on-site, its surface condition shall be examined to verify that it does not show any detrimental changes. A light surface layer of rust on the bars is not considered as being detrimental to its use. However, weight losses due to surface rusting, verified after wire-brushing to remove the adhering rust, shall not be accepted where they are greater than 1% of the initial sample weight.

When ready to be used, the surface of the reinforcement shall be free of any substances, such as grease, oil, paint, dust, soil or any other material that may adversely affect the steel or its bond capacity.

Article 32 Prestressing reinforcement

32.1 General

Prestressing is made of high-tensile strength steel, which is used to apply the prestressing force.

Its constituent elements may be: wires, bars or strands. The definition of these elements is as follows:

- Wire: A solid cross-section product that is manufactured by cold-drawing a wire rod, usually supplied in coils.
- Bar: A solid cross-section product that is only supplied in straight lengths.
- 2- or 3-wire strand: A set of two or three wires having equal nominal diameter *d*, in helical configuration, with the same pitch and same direction of twisting, around a common ideal axis (see UNE 36094:97).
- 7-wire strand: A set of six wires having equal nominal diameter *d*, in helical configuration, with the same pitch and same direction of twisting, around a straight core wire, the diameter of which is between 1.02 *d* and 1.05 *d* (see UNE 36094:97).

Tendon is a set of parallel prestressing reinforcement elements contained in a single duct which, during design, are considered as being a single reinforcement element. In the case of prestressed reinforcement, each of the individual reinforcements is a tendon.

COMMENTS

A tendon is also known as a stress unit. In addition to those materials mentioned in the article, which are the normal ones, there are others (for example, fibre-reinforced plastic) that may be used as prestressing reinforcement, and where its use shall be suitably justified in accordance with that established in Article 1.

32.2 Mechanical properties

For the purposes of this Instruction, the esential properties used to define the quality of prestressing steel are as follows:

a) Stress-strain diagram (unit load(tensile strength)-elongation, as a percentage).
b) Maximum unit load under tension (tensile strength) (fmax).
c) Yield stress (fy).
d) Concentrated residual strain at failure (eu).
e) Elongation under maximum load (emax).
f) Modulus of elasticity (Es).
g) Stricture (?), expressed as a percentage.
h) Reverse bend resilience (for wires only).
i) Relaxation.

j) Fatigue resistance.

k) Susceptibility to stress corrosion.

l) Skewed tensile strength (only for strands of rated diameter equal to or greater than 13 mm).

Producers shall provide guarantees for properties b), c), e), f), h) and i), at least.

COMMENTS

It is recommended that the content, in percentage, of each of the chemical constituents of prestressing steels , lies between the values given in Table 32.2, in order to achieve acceptable mechanical properties.

Table 32.2

Element	Minimum percentage	Maximum percentage
C	0.58	0.88
Mn	0.50	0.90
Si	0.15	0.40
P	--	0.040
S	--	0.040

The term of “unit load” is preferred over that of “stress” in order to take into account that the values recorded on the diagram refer to the initial section (unit load) and not the real (stress).

The yield stress, f_y for all types of steel is defined as the unit load corresponding to a residual strain of 0,2 percent. This value usually coincides with the flow range in those cases where it is present (Figure 32.2).

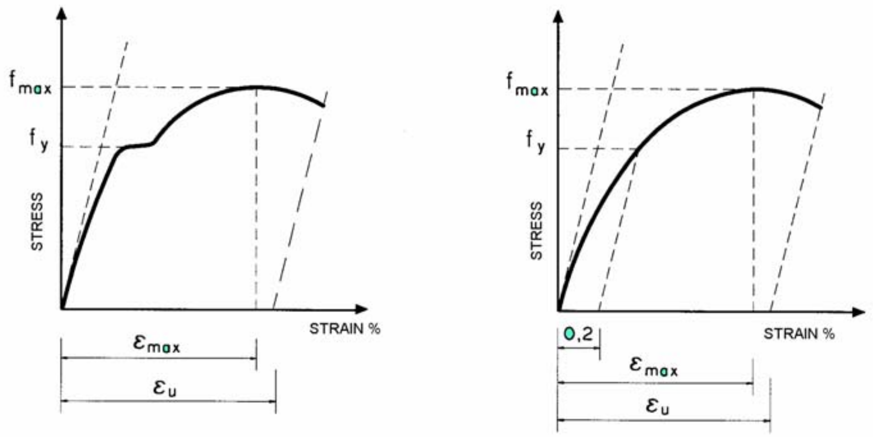

Figure 32.2

The residual elongation to failure may be evaluated in two ways. Firstly, by measuring over a base which, because it includes the failure section and adjacent zones, is affected by a possible stricture. The elongation measured in this way being called the “concentrated residual elongation”. Secondly, by measuring over a base that does not include the failure section nor any zones affected by a possible stricture, this is known as the “distributed residual elongation”.

The stricture, expressed as a percentage, is defined as:

$$\eta = \frac{A_i - A_u}{A_i} x\,100$$

where A_i and A_u, are, respectively, the straight, initial and failure sections.

Another parameter related to the ductility of the material is the sensitivity to notching, which is defined as the relationship between the load that a notched test bar is capable of supporting under tensile, with that supported by another, un-notched test bar with the same strength capacity as the first. This number is an index of the ability of the material to support defects that might be produced during production, transport or placing.

For those structures that should support dynamic or fatigue actions, where reinforcements are anchored through bonding, it is essential to know the anchorage lengths and the force transmission characteristics between the reinforcement and the concrete by means of special dynamic and static tests.

There is no single test method that enables the immunity of a given steel to stress corrosion to be determined with sufficient guarantee and in all conditions, when taking into consideration all the different aggressive environments that might lead to this phenomenon. It is therefore recommended that, whenever the existence of a specific, potentially aggressive environment capable of leading to this phenomenon can be foreseen, tests should be carried out (MELC standards) designed to provide information on the behaviour of the steel in certain aggressive environments (sulphides, chlorides and nitrates), or which indicate the level of susceptibility to hydrogen brittleness.

In special structures that might be subject to abnormal temperatures, it is essential to know how the mechanical specifications adopted for the project vary with temperature. A rise in temperature would increase the relaxation. A reduction in temperature would lead to a loss of ductility.

32.3 Wires

For the purposes of this Instruction, prestressign wires are those which comply with the technical requirements established in UNE 36094:97. Their mechanical properties, obtained from the tensile test carried out according to UNE 7474:92, shall meet the following requirements.

- The maximum unit load(tensile strength) $f_{máx}$ shall not be less than the values given in Table 32.3.a.

Table 32.3.a

Designation	Nominal diameter series, in mm	Maximum unit load (Tensile strength) $f_{máx}$,in N/mm², not less than
Y 1570 C	9.4 – 10.0	1,570
Y 1670 C	7.0 – 7.5 – 8.0	1,670
Y 1770 C	3.0 – 4.0 – 5.0 – 6.0	1,770
Y 1860 C	4.0 – 5.0	1,860

- The yield stress f_y shall remain between 0.85 and 0.95 of the maximum unit load(tensile strength) f_{max} This relation should be met, not only by the minimum guaranteed values, but also by the values corresponding to each of the wires tested.

- The strain at maximum load measured over a base with a length equal to, or greater than, 200 mm shall not be less than 3.5%. For wires intended for the manufacture of tubes, this strain shall be equal to, or greater than, 5%.

- Stricture at the yield point shall be equal to, or greater than, 25% in plain wires and clearly visible to the naked eye in the case of indented wires.

- The modulus of elasticity should be guaranteed by the producer within a tolerance of ± 7%.

In wires having a diameter equal to, or greater than, 5 mm or equivalent in section, the loss of tensile strength should not be greater than 5% after one reverse bend, carried out in accordance with UNE 36461:80.

The minimum number of reverse bends that the wire should be capable of withstanding,in accordance with UNE 36461:80, shall not be less than:

- For wires intended for hydraulic works, or subject to corrosive environments.	7
- In all other cases	3

The 1000 hour relaxation level at a temperature of 20° ± 1°C, for an initial stress equal to 70% of the guaranteed maximum unit load (tensile strength), as determined by UNE 36422:85, should not be greater than 2% (pre-straightened (decoiling) wires with stress-relieving treatment).

The nominal wire diameters , in millimetres, shall conform to the following series:

3 - 4 - 5 - 6 - 7 - 7,5 - 8 – 9.4 - 10

The geometric and weight properties of prestressing wires and their corresponding tolerances shall conform to the specifications given in UNE 36094-2:97.

COMMENTS

The mechanical properties of the wires are obtained, in general, by means of a patented heat treatment, followed by a drawing process and another for stress-relieve.

Whenever it is possible to choose between various diameters, under the same circumstances, it is recommended that the largest be employed in order to reduce the significance of any possible surface defects. In all cases, due to the special characteristics of small diameter wires, it is recommended, whenever possible, that when use isolated wires (in other words, those that do not form part of strands) as prestressing reinforcement, that these have a diameter of 4 mm or greater.

For information purposes, the producer may provide relaxation values corresponding to an initial stress of 60%, 70% and 80% of the maximum guaranteed unit load or the real. This may be determined using a sample adjacent to that subject to the relaxation test. When this information is not available, the relaxation values may be taken from Table 32.3.b(corresponding to 60%, 70% and 80% of the maximum real unit load) given in UNE 36094-2:97.

In a situation of employing wires with very severe straightening requirements, as occurs in the manufacture of railway sleepers, (diameters between 7 and 10 mm), the relaxation value shall be agreed between the producer and the customer.

When experimental results are not available, a modulus of elasticity of 200 kN/mm² may be taken. The real value may vary between 195 and 205 kN/mm² depending on the production process.

Table 32.3.b – Relaxation values

Initial stress as a percentage of the maximum unit load f_{max}		Relaxation
60%	of guaranteed f_{max}	1.3
	of real f_{max}	1.5
70%	of guaranteed f_{max}	2.0*
	of real f_{max}	2.5
80%	of guaranteed f_{max}	4.0
	of real f_{max}	4.5

* This value is the one required by the article.

32.4 Bars

The mechanical properties of the prestressing bars, which are obtained from the tensile test carried out according to UNE 7474:92, should meet the following requirements.

- The maximum unit load f_{max} should not be less than 980 N/mm^2.

- The yield stress f_y shall remain between 75% and 90% of the maximum unit load f_{max}. This relationship shall be met, not only by the minimum guaranteed values, but also by the values corresponding to each of the tested bars.

- The elongation at maximum load, measured over a base of length equal to, or greater than, 200 mm shall not be less than 3.5%.

- The modulus of elasticity shall be guaranteed by the producer within a tolerance of ± 7%.

The bars shall be capable of withstanding the bending test as specified in UNE 7472:89 without breaking or cracking.

The 1000 hour relaxation level at a temperature of 20º ± 1ºC, for an initial stress equal to 70% of the guaranteed maximum unit load, as determined by UNE 36422:85, shall not be greater than 3%.

COMMENTS

The bars employed as prestressing reinforcement are normally steel of a natural hardness. If the prestress unit load does not exceed 75% of the value corresponding to the yield stress, then the relaxation may considered as being practically nil.

Prestressing bars are only produced in a limited number of factories, and in general, for certain specific prestressing systems. It does not therefore, appear to be prudent to provide more detailed information on dimensions and qualities of bars, since this should be obtained from the actual producers themselves.

32.5 Strands

For the purposes of this Instruction, strands are those elements that meet the technical requirements established in UNE 36094:97. Their mechanical properties, obtained from the tensile strength test carried out in accordance with UNE 7326:88, shall comply with the following requirements.

The maximum unit load f_{max} shall not be less than the values given in Table 32.5.a, in the case of 2- or 3-wire strands, and 32.5.b in the case of 7-wire strands.

Table 32.5.a 2- or 3-wire strands

Designation	Nominal diameter series, in mm	Maximum unit load $f_{máx}$ in N/mm^2 not less than:
Y 1770 S2	5.6 – 6.0	1,770
Y 1860 S3	6.5 – 6.8 – 7.5	1,860
Y 1960 S3	5.2	1,960
Y 2060 S3	5.2	2,060

Table 32.5.B 7-wire strands

Designation	Nominal diameter series, in mm	Maximum unit load $f_{máx}$ in N/mm^2
Y 1770 S7	16.0	1,770
Y 1860 S7	9.3 – 13.0 – 15.2 – 16.0	1,860

- The yield stress f_y shall remain between 0.88 and 0.95 of the maximum unit load f_{max} This limitation shall be met, not only by the minimum guaranteed values, but also by the values corresponding to each of the elements tested.

- The elongation at maximum load, measured over a base of length equal to, or greater than, 500 mm should not be less than 3.5%.

- The failure stricture shall be visible to the naked eye.

- The modulus of elasticity shall be guaranteed by the producer within a tolerance of ± 7%.

- The 1000 hour relaxation level at a temperature of 20º ± 1ºC, for an initial stress equal to 70% of the guaranteed maximum unit load, as determined by UNE 36422:85, shall not be greater than 2%.

The deviation coefficient D value in the skewed tensile test (UNE 36466:91) shall not be greater than 28 for strands with a nominal diameter equal to, or greater than, 13 mm.

The geometry and weight properties of the strands, together with their corresponding tolerances shall conform to the requirements given in UNE 36094-3:97.

The wires used in the strands shall be capable of withstanding the number of reverse bends indicated in 32.3.

COMMENTS

Whenever it is possible to choose between various strands of differing wire diameters, under the same circumstances, it is recommended that the one with largest diameter be employed in order to reduce the significance of any possible surface defects.

The skewed tensile test consists of subjecting a specific length of strand, which is skewed at the centre by means of a mandrel, to a growing tensile stress, until at least one of the wires breaks. The objective is to determine the behaviour of the prestressed strand under multi-axial stress. In practice, non-straight strands or those that deviate at the anchorage are often subjected to this stress.

For informational purposes, the producer may provide relaxation values corresponding to an initial stress of 60%, 70% and 80% of the maximum guaranteed unit load or the real. This may be determined using a sample adjacent to the one which is subject to the relaxation test. When this information is not available, the relaxation values may be taken from Table 32,5.c, in which the relaxation values (corresponding to 60%, 70% and 80% of the maximum real unit load) are those given in UNE 36094-3:97.

Table 32,5.c – Relaxation values

Initial stress as a percentage of the maximum unit load (tensile strength) f_{max}		Relaxation
60%	of guaranteed f_{max}	1.3
	of real f_{max}	1.5
70%	of guaranteed f_{max}	2.0*
	of real f_{max}	2.5
80%	of guaranteed f_{max}	4.0
	of real f_{max}	4.5

* This value is the one required by the article.

When experimental results are not available, a modulus of elasticity of 190 kN/mm² may be taken. The real value may vary between 180 and 195 kN/mm² depending on the production process.

32.6 Supply

Wires are supplied in coils, where the reel diameter shall not be less than 250 times the diameter of the wire, and when left on a flat, horizontal surface they shall show a deflection of less than 30 mm in a 1 m length at any point along the wire.

The delivered coils shall not contain any welds that are carried out after the heat treatment prior to drawing.

Bars are supplied in straight lengths.

Two- or three-wire strands are supplied in coils, where the inside diameter should be equal to, or greater than, 600 mm.

Seven-wire strands are supplied in coils or on reels or spools which, unless established otherwise should contain a single produced length of strand. The inside diameter of the coil or the core diameter of the reel or spool should not be less than 750 mm.

Prestressing reinforcement shall be transported fully protected against moisture, deterioration, contamination , grease, etc.

COMMENTS

In the cases of both certified and non-certified products, the Instruction requires that quality control tests be performed on the steel (see Article 90) on acceptance, although test intensity will vary from one case to another.

With a reel diameter of not less than 250 times that of the wire, it can be guaranteed that the stress produced by the winding flexion in the outer fibre is maintained in the elastic zone of the material plus an acceptable safety margin.

The reel weight is usually between 500 and 2,500 kg. Bars are usually supplied in lengths between 12 and 14 metres.

The weight of reels used for supplying strands, including the actual weight of the strand, normally lies between 1,000 and 4,000 kg.

The produced length is understood as being the strand length that is usually produced with a single machine load.

32.6.1 Certified products

For steel in possession of a recognised quality mark or a Certificate of Compliance with Essential Requirements (CCER), both as explained in Article 1 of this Instruction, each delivery shall accredit its possession. It shall also be accompanied by the appropriate certificate of guarantee of producer, indicating the limit values for the various properties mentioned in 32,3, 32,4 and 32,5 in order to justify that the steel complies with the requirements contained in this Instruction.

Whenever requested, the producer shall also provide a copy of the results of the production control tests corresponding to the material delivered.

32.6.2 Non-certified products

In the case of products that do not possess a quality mark or a Certificate of Compliance with Essential Requirements (CCER) as explained above, each delivery shall be accompanied by the results of the tests corresponding to the mechanical properties and the geometric properties, performed by one of the CCER-issuing bodies mentioned in Article 1 of this Instruction, in order to justify the fact that the steel complies with the requirements laid down in 32,3, 32,4 and 32,5, as applicable.

32.7 Storage

To prevent the risk of oxidation or corrosion, the reinforcement shall be stored in ventilated areas protected from dampness from the floor and walls. All necessary precautions shall be taken in the warehouse to maintain the material clean and to prevent any deterioration of the steel due to chemical attack and nearby welding operations etc

Before storage, it shall be verified that the reinforcement is clean and without any spots of grease, oil, paint, dust, soil or any other material detrimental to its conservation or subsequent bonding capacity.

The reinforcement should be stored correctly classed by type, class and lot of origin.

The surface condition of all steel should be examined before use, especially after a long period of storage on-site or in the workshop, in order to ensure that no detrimental changes have taken place.

Article 33 Prestressing systems

The prestressing system supplier shall provide a technical report which contains all the information that needs to be known about that system, so that the design and execution of the work may be correctly performed.

Prestressing systems shall meet the requirements contained in UNE 41184:90.

Each type of anchorage requires the use of prestressing equipment. In general, the equipment recommended by the supplier of the system shall be used.

All the equipment used in the prestressing operations shall be in good working condition, so that its operation is in no way hazardous.

The force measuring devices incorporated in the prestressing equipment shall enable readings to be made with an accuracy of 2%. They shall be checked before being used for the first time and whenever necessary after this.

In the stressing beds of precast elements with pre-tensioned reinforcement, which is anchored by bonding, the prestressing shall be performed with the use of correctly tested equipment.

COMMENTS

The technical report referred to by the article shall contain at least the following:

- Description and specifications of the basic system elements (anchorage, joints , ducts, etc.), together with prestressing and injection equipment.
- type and properties of prestressing reinforcement to be used.
- Data for the location of tendons and anchorages.
- Friction coefficients and anchorage draw-in value (wedges , nuts, etc.), as applicable.
- Value of the efficiency coefficient of the anchored tendon.

Stressing devices used to perform the prestressing of the post-tensioned reinforcement steel, are usually hydraulic jacks.

The force measuring devices shall be suitable for the measurement of the working pressures of the jacks that are employed. When manometers are used, it is highly recommended that a precision type is employed, with safety devices to prevent water hammer.

Maximum guarantees in the prestress force measurement are obtained using interleaved dynamometers behind the jack, between the piston and the reinforcement being tensioned. In addition to hydraulic jacks, the prefabrication stressing beds for prestressing reinforcements may employ other devices.

Article 34 Anchoring and connections / couplers devices for post-tensioned reinforcement

34.1 Anchorage properties

The anchorage shall be capable of effectively restraining the tendons, resisting their ultimate unit load and transmitting to the concrete a load at least equal to the maximum load that the corresponding tendon is able to exert. For this reason, they shall meet the following conditions:

a) The effectiveness coefficient of an anchored tendon should be at least equal to 0.92 in the case of bonded tendons and 0.96 in the case of unbonded tendons.

b) Wedge anchoring systems should be capable of restraining the tendons in such a way that, once the wedges have ceased to be drawn in, the anchorage does not slip.

c) When the effects of fatigue or large variations in stress are liable to occur, suitable anchorages should be used that are capable of withstanding such action without rupture.

The design of anchorage plates and devices should guarantee that there are no points of deviation, eccentricity or loss of orthogonality between tendon and plate.

The tests required for verification of these properties are those described in UNE 41184:89.

The producer or supplier of the anchorages shall justify and guarantee their properties by means of a certificate, issued by a independent specialist laboratory, which specifies the conditions in which they are to be employed. In the case of wedge anchorages, it shall make a special point of the magnitude of the overall movement of reinforcement and the wedge, through adjustment and draw-in.

The elements that make up the anchorage should be subject to strict, effective control and should be produced in such a way that all pieces of the same type, system and size are interchangeable. In addition, they shall be capable of absorbing the dimensional tolerances established for reinforcement cross-sections without impairing their effectiveness.

COMMENTS

Bonded anchorages are calculated on the assumption that there is no tendon slip.

In order to reduce the anchorage length that results from the calculation, the tendons are terminated in a spiral or hook, or the ends are wave-shaped with the aim of increasing bonding with the concrete.

The use of passive anchorages in long tendons that are inaccessible after concreting, shall be carefully studied, since these tendons cannot be replaced, and if any problems arise during execution of the works, such as those caused by wire breakage of higher than forecast friction levels, these would be difficult to resolve.

The tensile breakage load for a tendon is in general, higher than that capable of being withstood by the tendon-anchorage combination.

The efficiency coefficient of a tendon is the ratio of the tensile breakage load of the tendon with its anchorage and the average value of the maximum load that the tendon alone is capable of withstanding in the standard steel tensile strength test. A higher efficiency coefficient is required in the case of non-bonded tendons due to the fact that an increase in force of these tendons is transmitted to the anchorage, whereas in the case of bonded anchorages, the same increase is distributed along the length of the tendon by the bonding.

Anchorage fatigue strength may be defined as the load amplitude that the same anchorage is able to withstand during 2×10^6 cycles, without causing any breakage which would involve a reduction exceeding 5% of the initial section of the tendon. As a minimum requirement, an anchorage capable of withstanding 2×10^6 cycles with an amplitude of 0.60 to 0.65 of the maximum tensile strength unit load of the tendon.

34.2 Connections / Couplers

Couplings for prestressing reinforcement shall meet the same conditions as those required of anchorages with regards to strength and effective restraint.

COMMENTS

Among the various types of connections / couplers that may be employed, there are, for example, those consisting of threaded sleeves (especially indicated in the case of bars), wedge sleeves, staples , coiled wires under tension etc.

34.3 Supply and storage

Anchorages and connections / couplers shall be delivered suitably protected so that they do not suffer any damage during transport, on-site handling or in storage.

They shall be stored correctly classified by size and all necessary precautions shall be taken to prevent corrosion, soiling or coming into contact with grease, insoluble oils, paint or any other harmful substance.

Article 35 Sheaths and accessories

In structural elements with post-tensioned reinforcement it is necessary to provide suitable ducts to enclose the tendons. The most common method is to use sheaths which may remain embedded in the concrete of the member or be removed once the concrete has hardened.

Metal sheaths are the most frequently used type. In general, they are metal tubes with ribs or corrugations on their outer surface to enhance their bond with the concrete and to increase stiffness. They should be sufficiently resistant against crushing so that they do not become deformed or dented during on-site handling or under the weight of fresh concrete or accidental knocks etc. They shall also be able to withstand contact with internal vibrators without any risk of being perforated

Under no circumstances shall they allow cement slurry or mortar to enter during concreting Therefore the connections / couplers both between lengths of sheath and between sheath and anchorage must be perfectly watertight.

The inner diameter of the sheath should be sufficient to allow grouting to be correctly carried out, while taking into consideration the type and cross-section of the reinforcement to be housed inside.

The most commonly used accessories are as follows:

- Grout vent. A small piece of piping that connects the prestressing ducts to the exterior, generally placed at the high and low points of their profile to facilitate the removal of air and water from inside the ducts and to follow the progress of the grout. It is also called a breathing hole.

- Grouting nozzle. A part through which the grout may be injected into the ducts enclosing the prestressing reinforcement.

- Profiler. An element that is generally made of metal or plastic, which is used in some cases to uniformly distribute the various constituent parts of the tendon within the duct.

- Coupling sleeve. This is a piece that is usually in the form of a truncated cone which connects the bearing plate to the sheath.

- Lining sleeve. A pipe, generally made of polyethylene with an external diameter rather smaller than the inside of the sheath, into which it is inserted to ensure a smooth profile.

In some prestressing systems, the coupling sleeve is integrated into the bearing plate and has a characteristic shape.

Similar precautions should be taken for the supply and storage of sheaths and accessories as those for the reinforcement.

COMMENTS

Among those types of sheath that are recovered once the concrete has hardened, mention should be made of those consisting of inflatable rubber tubes, of a suitable strength and which overhang the ends of the pieces. To remove them, they are first deflated, then one end is pulled to extract them. They may even be employed in very long pieces and with reinforcement having a straight, polygon cross sectional or curved profile.

To obtain the necessary watertight properties in the metal sheath connections/couplers, it is recommended that they be sealed with adhesive tape or any other similar procedure. Special sealing compounds that guarantee the necessary watertight properties may be employed at difficult points along the profile, or where they are coupled to the anchorage.

In general, correct grouting is obtained when the inside diameter of the sheath is greater than that of the tendon in encloses by at least 5 to 10 mm. In addition, it is also advisable that the ratio of the sheath section to that of the reinforcement be in the order of 1.5 to 2. In the case of non-circular sheaths (for example, those with an oval section), the inside dimensions of the sheath should exceed that of the tendon by at least 5 to 10 mm.

The inlets arranged along the length of the sheath profile should also permit the evacuation of any water that might be remaining after the washing operation, before reinforcement insertion or grouting. Special T-shaped accessories are employed for the formation of these inlets and those in the grout vents.

Both the sheath profilers and the coupling sleeves with the anchorages may be of various types. Generally speaking, each prestressing system has adopted a characteristic model.

All plastic parts and accessories should be chloride free (see 37.3).

Article 36 Grouting products.

36.1 General

In order to guarantee the protection of prestressing reinforcements against corrosion, in the case of tendons enclosed in ducts or sheaths arranged inside members, the ducts or sheaths should be filled with a suitable grouting product.

Grouts should be free of substances such as, chlorides, sulphides , nitrates, etc., that may be detrimental to the reinforcement, the grout itself or the concrete of the member.

Grouting products may be bonding or non-bonding and should meet the requirements given in 36.2 and 36.3 respectively.

COMMENTS

Prestressing steel is especially sensitive to any substance that might cause or encourage corrosion, not only because of its larger specific area compared to reinforcing steel, but also, more significantly, because of the high state of stress to which it is subjected after stressing.

36.2 Bonding grouts

In general, these products shall be cement-based slurries or mortars and their constituents shall satisfy the following requirements:

- The cement used shall be Portland, type CEM I. Special justification would be required for the use of other types of cement.

- The water shall not have a pH of less than 7.

- When aggregates are used in preparing the grout, they shall consist of silica or limestone particles, free from acid ions and laminar particles such as mica or slate.

- Admixtures may be used if it can be demonstrated, by means of suitable tests, that their use improves the performance of the grout, for example, by making it easier to inject, reducing a tendency to segregate, serving as an air-entraining agent or causing controlled expansion of the slurry. In all cases, the provision of the second paragraph of 36.1 shall be taken into account. In all cases, the contents of the second paragraph in 36.1 shall be taken into consideration.

- The water/cement ratio shall be as low as possible while still compatible with the need to obtain the fluidity required for proper grouting.

- Bleeding of the grout mortar or slurry, as determined in accordance with the "Test method for determining grout stability" described in Annex 6 of this Instruction, should not exceed 2% by volume three hours after preparation of the mixture. In certain exceptional cases a maximum of up to 4% may be accepted. Moreover, the exuded water should be reabsorbed within twenty-four hours.

- The reduction in volume of the mix should not exceed 3%, and any expansion in volume should be less than 10%. These values should be determined in accordance with the same "Test method for determining grout stability" stated in the previous paragraph.

- The 28-day compressive strength of the grouting mix should not be less than 30 N/mm2 (see Article 98).

Apart from cement pastes and mortars, other materials may be used as bonding grouts provided their suitability has been sufficiently justified by means of thorough testing.

COMMENTS

The purpose of filling the ducts with bonding grout is to protect the prestressing reinforcement and to provide suitable bonding between this and the concrete of the member.

It is advisable for the reinforcement to be enclosed within a material with a high alkalinity in order to prevent corrosion. For this reason the use of Portland cement, type CEMI is recommended, except in fully justified situations.

In general, the mixing of the grout mortar or slurry shall be energetic, in order to obtain an well-worked material, with, if possible, a colloidal nature.

If the grouting material is a mortar, their grading shall be practically continuous, since any discontinuities would encourage separation of the aggregate and the slurry during grouting operation, giving rise to the formation of sand pockets which would make perfect sheath filling difficult.

On the other hand, experience has shown that clean, rounded, silica sands increase the grouting ability of the mortar due to the round grain shape.

As far as the water/cement ratio is concerned, it is advisable for this to be reduced, not only for reasons of mechanical strength, but also for other motives, such as frost resistance and the shrinkage of the grouting material. Experience has shown that, for a pure mixture of cement and water, the ideal water/cement ratio lies between 0.38 and 0.43. For other types of mixtures, it would be necessary to determine the correct water/cement ratio in each particular situation.

Frost resistance of the grout mortar or slurry may be considered as being satisfactory if the grouting product contains a minimum of 3% of air bubbles once the segregated water has been reabsorbed.

The fluidity of the grout mortar or slurry, together with its water retaining capacity condition the perfect silting of the ducts or sheaths. An increase in fluidity facilitates the grouting operation, but might later cause greater bleeding of the grouting material and, in consequence, defective duct filling.

Therefore, if the fluidity that produces maximum admissible bleeding is not sufficient for the grouting operation, it will be necessary to employ an aero-fluidicizer, without adding more water to the mortar, or to employ a finely divided material, such as trass or diatomaceous earth etc., which would enable the mixing water to be increased and, consequently, the fluidity, without an increase in bleeding, since these finely divided materials improve the water retaining capacity.

The fluidity of the grout mortar or slurry may be measured by the amount of time that a certain volume of the grout mortar requires to emerge from a viscosimeter. Other procedures may also be employed, always provided that they are proven to be suitable for the purpose through testing.

In accordance with its fluidity, each mixture type has a specific field of application. The lower limits of fluidity are, in general, given by the need to obtain sufficient grouting ability and the upper ones are due to the requirement in relation to the compressive strength, the reduction in volume and bleeding.

36.3 Non-bonding grouts.

These products consist of bitumens, bituminous mastics, soluble greases or, in general, any material that is suitable for providing the prestressing reinforcements with the protection they require, but without any with ducts.

In order for their use to be authorised, appropriate tests that guarantee their suitability shall previously have been carried out.

COMMENTS

Non-bonding grouting products are employed in structures with exterior prestressing, in those cases of temporary protection for the prestressing reinforcement when it is necessary to re-tensioning in order to carry out continuous stress controls and in other similar circumstances.