4. STRENGTH APPROXIMATION

4.1 General

In Fig. 4.1.1, the part (tab) of the logical flowchart of EUCON® for a first approximation of the concrete strength is presented. The tab contains:

- a field that the user is mainly informed on the main concrete characteristics that influence its strength and introduces some **input data** regarding efficiency factors of silica fume and/or fly ash, if they added.
- a **calculation button**, and
- a field of the output results presenting the mean compressive strength and the strength class.
- There is also an *optional field* that the user may introduce the compressive strength test results for cement on mortar specimens (according to EN 196-1) that give the strength ratio 2/28 days, and the strength development (with drawing option).

CONCRETE STRENGTH

INPUT

Tab "MIX DESIGN" data

Tab "PHYSICOCHEMICAL CHARACTERISTICS" data

Main concrete characteristics that influence strength (in addition: efficiency factors of additions, silica fume and/or fly ash, if added)

▼

CALCULATION

(Mean compressive strength, strength class, strength ratio 2/28 days, strength development)

Figure 4.1.1 Logical diagram for computer calculation of the concrete strength.

A general view of this tab is given as Fig. 4.1.2. The user has to fill in the "white boxes" or to accept the default values (only in the case when silica fume and/or fly ash are added as concrete additions), and then to press the calculation button in order to have a first approximation of the concrete strength. For the algebraic formulae used for these calculations and further questions, **please always advise the *Theoretical Background* [1], chapter 4**. In the sequence, each part of this tab is discussed in detail.

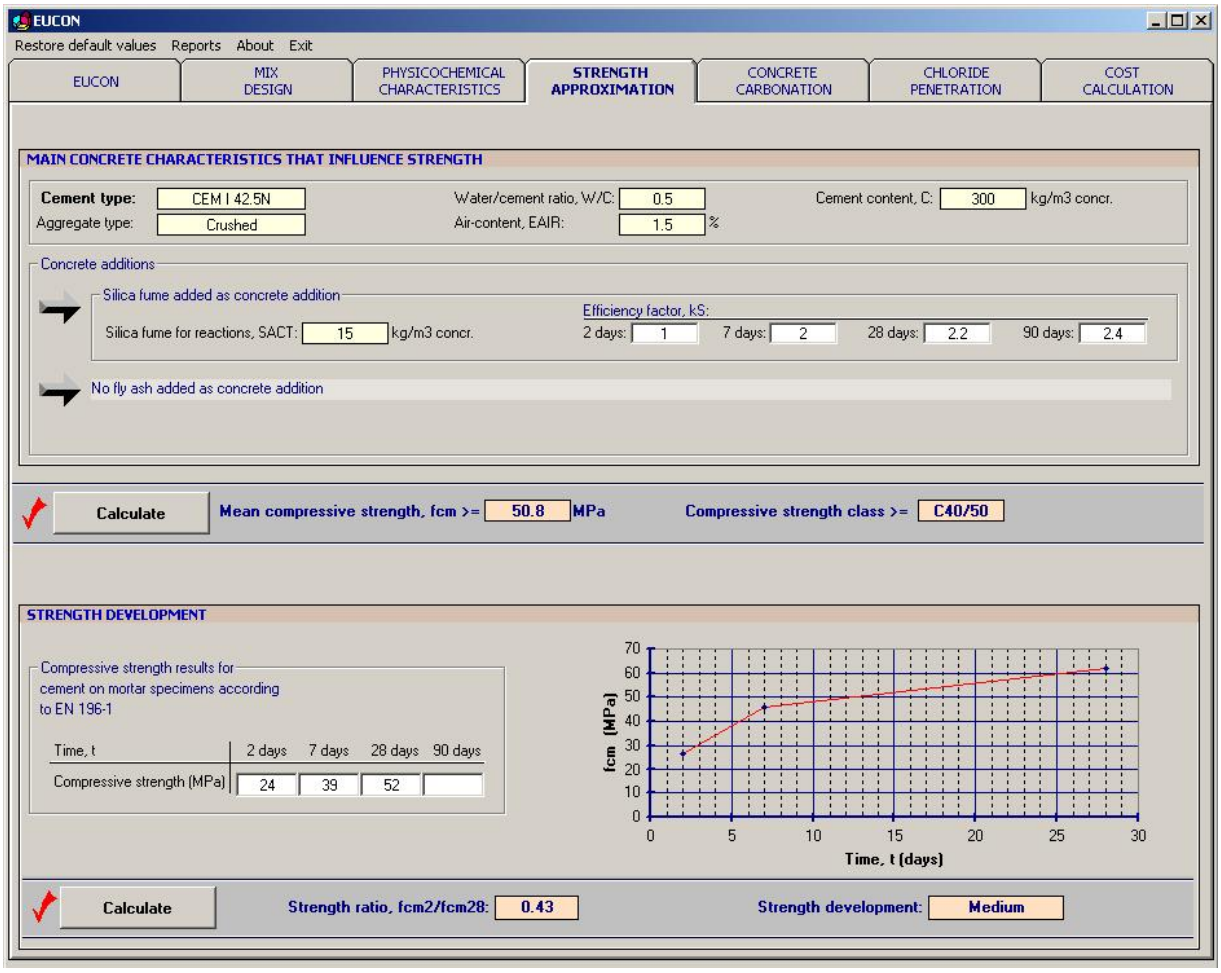

Figure 4.1.2 General view of the tab "STRENGTH APPROXIMATION" of the EUCON® program.

4.2 Main concrete characteristics that influence strength

Concrete composition

Cement type:	It is a reminder for the cement type used (see tab "MIX DESIGN").
Water/cement ratio, W/C:	It is a reminder for the water-to-cement ratio used (see tab "MIX DESIGN").
Cement content, C:	It is a reminder for the total cement content in the concrete volume, kg/m^3 (see tab "MIX DESIGN").
Aggregate type:	It is a reminder for the aggregate type used (see tab "MIX DESIGN"). The aggregate type can be crushed or rounded. The rounded aggregates decrease the concrete strength by a factor of 13%, in comparison to the crushed ones [1].
Air content, EAIR:	It is a reminder for the total entrained and entrapped air content in the concrete volume, % (see tab "MIX DESIGN").

Efficiency of additions

Silica fume or fly ash for reactions, SACT or FACT:	It is a reminder of the amount of silica fume or fly ash (when used as concrete additions) that can participate in the pozzolanic reactions (active part), kg/m^3 (see tab "PHYSICOCHEMICAL CHARACTERISTICS").
Efficiency factor of silica fume (kS) or of fly ash (kF):	The efficiency factor (or k-value) is defined as the part of the silica fume or fly ash that can be considered as equivalent to portland cement (CEM I), providing the same concrete properties (obviously k=1 for portland cement). Introduce here the efficiency factors for silica fume (kS) or for fly ash (kF), at the various ages after cast, 2, 7, 28, and 90 days. Use the default values, if you do not have more accurate experimental results. The values at 28 days influence the mean compressive strength. UNITS: dimensionless LIMITS: $0 \leq kS \leq 4$ and $0 \leq kF \leq 2$ DEFAULT VALUE: These in Table 4.2.1

Table 4.2.1 Efficiency factors (k-values) for various supplementary cementing materials (data from [1])*.

Cementitious/ pozzolanic materials	Strength (2 days)	Strength (7 days)	Strength (28 days)	Strength (90 days)
Portland clinker	1	1	1	1
Silica fume	1	2	2.2	2.4
Pozzolana (natural)	0.4	0.3	0.3	0.3
Metakaolin	1	1.8	3	3
Siliceous fly ash	0.2	0.3	0.5	0.7
Calcareous fly ash	1.1	1.1	1.2	1

* All these SCM were ground prior to use up to a fineness of 400±20 m^2/kg according to Blaine's test.

4.3 Calculations

For the algebraic formulae used for these calculations and the theory that they based on and for further questions, **please advise the *Theoretical Background* [1], chapter 4**. Click on the "**Calculate**" button to estimate:

Mean compressive strength, fcm ≥	The mean compressive strength of concrete should be greater than the estimated value. The estimation is based on the modified Feret's formula (4.3.1) of the reference [1]. UNITS: MPa
Compressive strength class ≥	According to EN 206 [3], the hardened concrete *is classified* with respect to its *compressive strength* according to Table 4.3.1. The characteristic compressive strength at 28 days of 150 mm diameter by 300 mm cylinders ($f_{ck,cyl}$) or the characteristic strength at 28 days of 150 mm cubes ($f_{ck,cube}$) may be used for classification. *Characteristic strength* is the value of strength below which 5% of the population of all possible strength determinations of the volume of concrete under consideration, are expected to fall.

Table 4.3.1 Compressive strength classes for normal-weight and heavy-weight concrete.

Compressive strength class	Minimum characteristic cylinder strength ($f_{ck,cyl}$, MPa)	Minimum characteristic cube strength ($f_{ck,cube}$, MPa)
C8/10	8	10
C12/15	12	15
C16/20	16	20
C20/25	20	25
C25/30	25	30
C30/37	30	37
C35/45	35	45
C40/50	40	50
C45/55	45	55
C50/60	50	60
C55/67	55	67
C60/75	60	75
C70/85	70	85
C80/95	80	95
C90/105	90	105
C100/115	100	115

If the **strength development of the concrete** is required, then the user has to fill in the table at the lower-left corner of the tab with the compressive strength test results for cement on mortar specimens (according to EN 196-1; if available) and then to calculate the strength ratio 2/28 days, and the strength development (with drawing option).

Strength ratio, fcm2/fcm28:	The ratio of the mean compressive strength after 2 days ($f_{cm,2}$) to the mean compressive strength after 28 days ($f_{cm,28}$). UNITS: dimensionless
Strength development:	Information on the *strength development* of the concrete either in terms of Table 4.3.2 or by a strength development curve at 20 ^{o}C between 2 and 90 days.

Table 4.3.2 Strength development of concrete at 20 °C.

Strength development	Estimate of strength ratio ($f_{cm,2}$ / $f_{cm,28}$)
Rapid	≥ 0.5
Medium	≥ 0.3 to < 0.5
Slow	≥ 0.15 to < 0.3
Very slow	< 0.15

By obtaining the above estimation for the concrete strength, the user may:

- **accept these results** and continue in the next tabs to estimate service life and cost.
- Otherwise, **you may change any input data mainly from the tab "MIX DESIGN"** in order to correct the output results of this tab, **until final acceptance.**
- **In general, it has to be emphasized that all the above approach is just *a first rough approximation*, valuable for the initial test proportioning, and a detailed experimental verification is further required.**