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THE SUMMARY OF DOCTORAL THESIS

THE TITLE OF THESIS : Multicriteria evaluation of the concrete stations performance level, equipped with real-time parameters processing and monitoring systems

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INTRODUCTION

1.The opportunity and the objectives of the doctoral thesis

The quality of concrete prepared in concrete batching plants is an essential requirement for ensuring the quality level of fresh concrete works, with a major impact on the life quality by ensuring the operational safety of the buildings.The characteristics of concrete are negatively influenced by a number of non-conformities of concrete batching plants, being necessary a detailed analysis of plants for these non-conformities identification.

The thesis opportunity results from analysis of the concrete batching plants in our country using technical inspection and the performance level multicriteria evaluation regarding real-time parameters monitoring, especially for automated concrete stations, possibly equipped with GPS tracking systems for concrete truck- mixers.

The main objectives of this doctoral thesis are:

- the need to modernize concrete stations with manual control;
- performance level evaluation for different automated concrete stations analyzed, regarding the processing capacity, monitoring and recording of the main parameters;
- effect study of the implementation GPS programs for concrete truck- mixers;
- operational reliability study for concrete stations;
- mathematical modeling of the kneading process, for the case of mixers with vertical axis;
- the working mode analysis at the concrete recipes preparation on a concrete stations group, with determination by experimental method of the main parameters called cumulative, followed by checking their compliance with norms, technical regulations and standards;
- determination by mathematical and experimental method and validation the relations between the mixing time and the concrete compressive strength at 28 days.

2.The capitalizition on research results

The final research results could be used by all construction contractors which have to put in work fresh concrete and will aim to demonstrate the need to modernize manually operated concrete plants, the need to improve working methods in automated concrete plants, and the need to carry out technical inspections at all concrete stations in operation.

CHAPTER I

CURRENT STAGE OF RESEARCH IN THE PARAMETERS REAL-TIME MONITORING FIELD FOR CONCRETE STATIONS

1. Main requirements and performance level

The main requirements and the performance level of concrete plants are closely correlated with their ability to monitor in real time the parameters, in order to ensure their compliance with deviations imposed by regulations and norms. In order to meet these requirements, it is recommended that concrete plants to be equipped with the following:

- automatic control systems, equipped with process computer and printer;
- dosing correction systems during the concrete batches preparation;
- monitoring systems of effective mixing time.

2.Concrete stations in operation in Romania, concrete stations manufacturers

The manually controlled concrete stations are manufactured in our country by UBEMAR Ploiești and NICOLINA Iași. Examples of concrete stations manufactured by UBEMAR Ploiești: CEDOMAL 15, CEDOMAL 51, CEDOMAL 51A, CEDOMAL 52. Examples of concrete stations manufactured by S.C. NICOLINA S.A Iași: CB 22, CB 45.

Examples of Romanian companies that modernize or produce automated concrete stations: UNISERV INTERNATIONAL and CEDOMSERVICE from Ploiești, PROSOFT INDUSTRY from Săvinești.

Internationally, there is a major concern of concrete plant manufacturers regarding parameters real-time monitoring at automated concrete plants.

The German companies LIEBHERR and STETTER, as well as the Italian companies SIMEM, SCM 2 and OCMER occupy the first places in Romania, as a number of automated concrete stations in operation. Examples of concrete stations such as LIEBHERR type COMPACTMIX 1.0 and BETOMIX 2.25, STETTER type M 1 and M 2, as well as the new Italian MARCANTONINI stations type B 4, all as stations with high levels of performance.

Other companies producing automated concrete plants that can be mentioned are: TEKA-GERMANY, FRUMECAR and LEBLAN-SPAIN, CIFA-ITALY. Manufacturing companies from Eastern Europe present in our country: ARMODINAMIKI and TEXNOKAT - GREECE, SIMI - SERBIA, ELKON and CONSTMACH - TURKEY.

According to the mixing system, the manufactures can be exemplified as follows [15,16]:

- mixers with vertical axis, companies LIEBHERR, STETTER, FRUMECAR, TEKA;
-mixers with two vertical axis, companies SICOMA, OCMER, HAARUP and TEKA;
-mixers with two horizontal axis, companiesSTETTER, LIEBHERR, SICOMA, SIMEM.

According to the mixing time recommended by the manufacturers, we can list:

- vertical shaft mixers, type LIEBHERR, STETTER and FRUMECAR have a minimum mixing time of 30 seconds, regardless of the useful capacity provided [15,16];
- SICOMA and OCMER type mixers with two vertical / horizontal axis and OCMER type mixers (with two vertical axis) have the recommended time of 40 seconds for fluid concretes and 60 seconds for dry concretes [14,16];
- SIMEM mixers with two horizontal axis have a mixing time of 30 - 35 seconds for fluid concrete and 60 seconds for dry concrete [16].

The OCMER concrete stations and the concrete stations with SICOMA mixers have recommended cycle times of 90 seconds (at the recommended mixing time of 40 seconds) and also 120 seconds (at the recommended mixing time of 60 seconds) [14,16] .

CHAPTER II

COMPARATIVE STUDY OF PERFORMANCE LEVEL FOR VARIOUS CONCRETE STATIONS

Figure 2.1. Process computer with technological flow display at a concrete plant, model PROMIX. Dosing and mixing parameters are displayed instantly while working, but batch protocols delivery and listing are not possible.

Figure 2.2. Specialized control software, with technological flow display and parameters real-time monitoring, at a concrete station model LIEBHERR. The software includes batch protocols files, and the system is equipped with a printer to list them.

At the modernized CEDOMAL 15 concrete plant shown in figure 2.3, the dosing parameters , the mixing and discharging processes can be monitored.

In the figure 2.4 at position 35 it is shown the absorbed power indicator band, power correlated with the consistency of the concrete, at a LIEBHERR concrete plant [18].

Figures 2.5-2.7 show extracts from various batch protocols from LIEBHERR concrete stations. In figure 2.6- extract from the batch protocol from a BETOMIX station 2.25. Figure 2.7 shows a batch protocol from a BETOMIX 2.0 R station, with a longer service life.

It can be seen from figures 2.6 and 2.7 that the BETOMIX 2.25 concrete plant, of more recent manufacture, offers more information than the BETOMIX 2.0 R station.

As a **general conclusion**, automated concrete plants can present a multitude of monitoring systems with different performance levels related to cumulative parameters.

Fig.2.1- Tehnological flow at a PROMIX station

Fig. 2.2- Command software for a LIEBHERR station

Fig. 2.3 Tehnological flow CEDOMAL 15 station

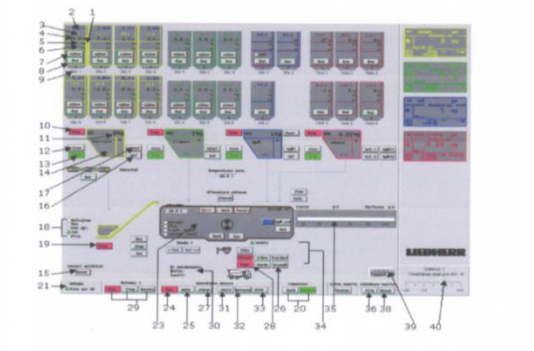
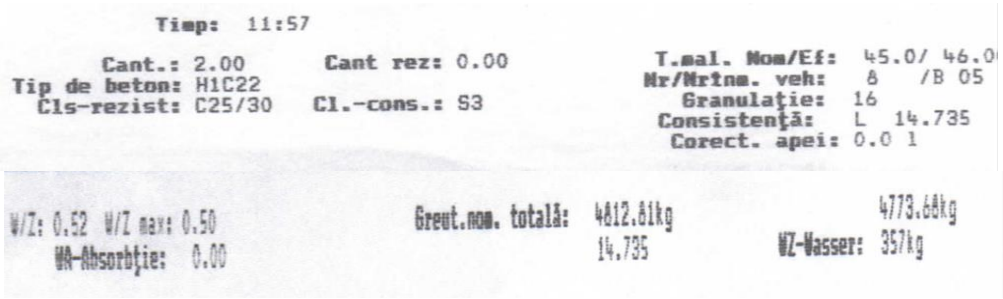


Fig.2.4- Tehnological flow LIEBHERR station



Timp: 11:57

Cant.: 2.00 Cant rez: 0.00
Tip de beton: H1C22
Cls-rezist: C25/30 Cl.-cons.: S3

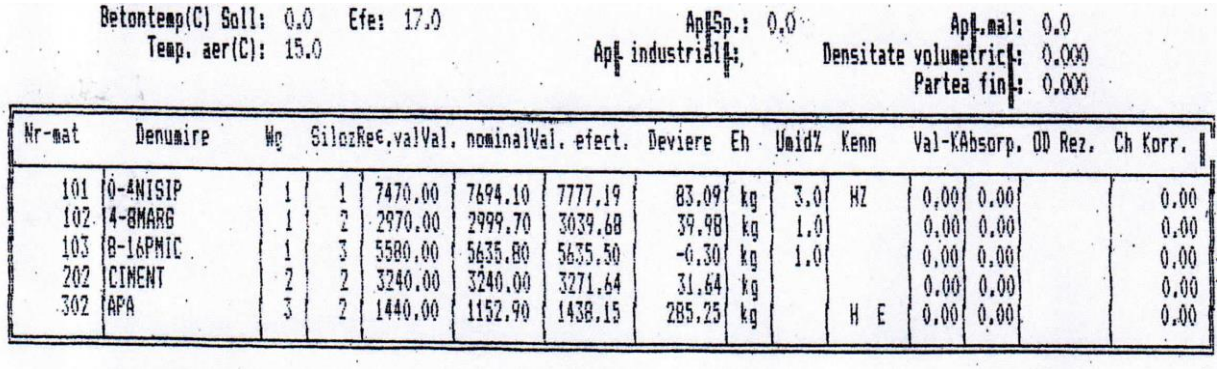
T.mal. Nom/Ef: 45.0/ 46.0
Nr/Mrtnm. veh: 8 /B 05
Granulaţie: 16
Consistenţă: L 14.735
Corect. apei: 0.0 1

W/Z: 0.52 W/Z max: 0.50
WA-Absorbţie: 0.00

Greut.nom. totală: 4812.81kg
14.735

4773.68kg
WZ-Vasser: 357kg

Fig. 2.5- Extracts from various batch protocols - LIEBHERR concrete stations



Betontemp(C) Soll: 0.0 Efe: 17.0
Temp. aer(C): 15.0

Apă Sp.: 0.0
Apă industrială:

Apă mal: 0.0
Densitate volumetrică: 0.000
Partea fină: 0.000

Nr-mat	Denumire	Wg	Silozrec	valVal. nominal	Val. efect.	Deviere	Eh	Umid%	Kenn	Val-KAbsorp.	OD Rez.		Ch Korr.
101	0-4NISIP	1	1	7470.00	7694.10	7777.19	83.09	kg	3.0	HZ	0.00	0.00	0.00
102	4-8MARG	1	2	2970.00	2999.70	3039.68	39.98	kg	1.0		0.00	0.00	0.00
103	8-16PMIC	1	3	5580.00	5635.80	5635.50	-0.30	kg	1.0		0.00	0.00	0.00
202	CIMENT	2	2	3240.00	3240.00	3271.64	31.64	kg			0.00	0.00	0.00
302	APA	3	2	1440.00	1152.90	1438.15	285.25	kg		H E	0.00	0.00	0.00

Fig. 2.6 Batch protocol from a BETOMIX 2.25 LIEBHERR station

Start dozare: 09:19
Sfirsit dozare: 09:32

Marca beton — Granulatie max.: 16 — Consistenta: S3
Atribute: — Unde se foloseste:

0,53

Lufttemp.: 14 °C um 06:45 Uhr

	SORT 0-4	MOI	SORT 4-8	MOI	SORT 8-1	MOI	CEM II/A	APA REC.	APA POTA	MOW	SIKAPLAS
CH 1	01250 kg	15,0%	00600 kg	1,20%	00980 kg	0,80%	00520 kg	00056 kg	00042 kg	00178 kg	02,80 kg
CH 2	01320 kg	14,8%	00620 kg	1,20%	00970 kg	0,80%	00523 kg	00053 kg	00039 kg	00185 kg	02,90 kg
CH 3	01330 kg	14,5%	00600 kg	1,20%	00980 kg	0,80%	00521 kg	00056 kg	00041 kg	00183 kg	02,95 kg
CH 4	01260 kg	12,5%	00600 kg	1,20%	00950 kg	0,80%	00521 kg	00055 kg	00066 kg	00154 kg	02,75 kg
CH 5	01250 kg	11,9%	00580 kg	1,20%	00970 kg	0,80%	00522 kg	00055 kg	00072 kg	00148 kg	02,90 kg
SAct	06410 kg		03000 kg		04850 kg		02607 kg	00275 kg	00260 kg	00848 kg	14,30 kg
SNom	06390 kg		03000 kg		04850 kg		02605 kg	00275 kg	00260 kg		14,25 kg
DIFE	00020 kg		00000 kg		00000 kg		00002 kg	00000 kg	00000 kg		00,05 kg

Apa: SAct: 01383 kg SNom: 01373 kg DIFERENTA: 00010 kg Solids: 00,00 %

Fig. 2.7- Batch protocol from a concrete station LIEBHERR BETOMIX 2.0 R

CHAPTER III

COMPARATIVE ANALYSIS OF OPERATING BEHAVIOR AND RETURN TO OPTIMAL INITIAL PARAMETERS AFTER FAULTS REPAIR FOR VARIOUS AUTOMATED CONCRETE STATIONS

Case 1. Modernized CEDOMAL 15 concrete plant - Fig 2.3 [17]

When faults occur in the component dosing equipments in automatic system, they can be observed in the dosing control software (figure 2.3) or on the batch protocol. Some warning light signals for malfunction may be detected during operation (for example, the mixer discharge valve is blocked - it does not open or close).

When a simple fault is found during work in automatic system, the operator will proceed to solve the problem as follows:
- the PAUSE key is used to restart the general system;
- the ESC key is used to restart the dosing system;
- the STOP key is activated to stop the station;
- actions are taken to remedy the simple blockages / faults found;
- after remediation, the concrete preparation in automatic system is continued, with the finishing of batch on load at the time of the failure and then with the others scheduled batches.

In the event of more serious malfunctions, the concrete production in automatic system can no longer continue. To remedy this, it proceeds as follows:
- the transition to the manual operating system is made by pressing the button-switch;
- it press START to end the current batch in manual system and it release a batch protocol only for the quantity prepared until the station is stopped;
- after completing the respective charge, the station stops with the STOP button;
- the detected fault is identified and remedied;
- it pass to the automatic system by the switch button and it restart the station by the START button, resuming production in automatic system.

Case 2. Automated concrete plant PROMIX M 80 S - Fig 2.1 [17]

The PROMIX M 80 S station presents faults warning messages, referring to the faults encountered in the electrical equipment or in the automation system, which can be diagnosed with the “CONFIRM DAMAGE” key help. In the command software may also appear warning messages in the malfunction case on the mixer concrete discharge system (the valve is blocked).The displayed messages do not disappear from the computer display, until the respective operating disturbances have been eliminated. After the respective technical

problems solving with the electrical / automatic systems, in order to resume the production it is necessary to press the UPDATE key for the system restart.

The other damages types are not signaled by messages but the operator can be detected them, for example by the appearance of unusual values at dosing. Unlike the modernized CEDOMAL 15 station, the PROMIX M 80 S station does not provide batches protocols.

In the event of a minor fault (a slight disturbance in the software) the control system can be switched off and reset (UPDATE key). After the problem solving, it will proceed to the end of the batch where the fault occurred, then to the next batch preparation in automatic mode. In case of a major failure, the station will stop and use the manual command on the software (the station switches from automatic mode to manual system through the "COMMAND SELECTION" button), to complete the last batch, then the production is stopped.

Case 3. Concrete station LIEBHERR BETOMIX 2.25

The LIEBHERR concrete plant operator has at his disposal warning signals during work regarding the occurrence of any operating problems, such as: temporary clogging of the water / additive pumping pipes, dosing bunkers that do not empty, valves that do not open / close. The faults can be found in a software page with specified malfunctions; they are therefore confirmed by the software after their display by signals on the screen, and can be diagnosed in order to fix them as soon as possible.

The LIEBHERR concrete plant is equipped with software for automatic shutdown command in the event of faults with a major impact on operation, such as:

- stopping or clogging the cement screw;
- the pneumatic cylinder for the dosing valve actuating is out of order;
- electric motor of the mixer with limit protection;
- the skip cable is not energized, the skip does not work, operation stopped;
- a defective weighing dose.

The LIEBHERR BETOMIX 2.25 station also has an effective manual control system, operating in case of breakdowns, by activating the Man key. Possible errors in the concrete parameters can be easily identified when printing the batch protocol - see figure 2.6.

Conclusions resulting from the analysis of the three cases presented:

- the three stations analyzed offer to their operators efficient ways to detect possible faults in a good time manner;
- the LIEBHERR concrete plant is superior to the other two, in terms of the detecting and diagnosing possible faults;
- the batches protocol is missing in the PROMIX M 80 S case and it doesn’t contain details about the mixing time, as well as other parameters in the modernized CEDOMAL 15 case;
- the solving ways of the malfunctions and returning to the initial parameters are similar for the three stations, the LIEBHERR station having a higher capacity in this matter.

CHAPTER IV

MATHEMATICAL MODELLING OF THE MIXING PROCESS IN THE CASE OF VERTICAL AXIS MIXERS WITH FORCED KNEADING

Introduction. In order to mathematically model the mixing process, the case of two mixers with vertical axis was considered, TEKA model type BAF 750 l and BAF 1500 l, presented in figures 4.1 and 4.2. The modelling took into account the pallets vibrational movement, under the mixer arm bending impulse, considered as an embedded beam, bending produced by the concrete mass in front of the pallet and in front of the arm portion inside the concrete mass during mixing, at which it adds the own masses of the pallet and the arm portion.

The arm-pallet system movement was considered to be forced vibration of a viscous damping system, subjected to harmonic excitations [4]. The kneading process mathematical

modelling aimed the determining of bending forces and arrows, implicitly the own pulsations for each pallet, as well as the resulting movement amplitudes.

IV.1 Case of the TEKA 750 l mixer. Calculation of the own pallets pulsations and of the movement amplitudes [20]

Figure 4.1. Schematic representation of the TEKA BAF 750 l mixer, with a useful capacity of 0.5 m^3, having the following technical characteristics: productivity 25-30 m^3/h, motor power 22 kW, rotor speed 29 rpm, number of pallets: 6 pieces [13]

Technological and dimensional characteristics for the TEKA mixer shown in figure 4.1:

- diameter of the mixer arm d = 32 mm,
- axial resistance modulus $I_z = \frac{\pi d^4}{64} = 5.14 \text{ x}10^4\ mm^4$
- pallets radiuses: R_1= 882 mm; R_2= 814 mm; R_3= 807 mm;
  R_4= 730 mm; R_5= 675 mm; R_6= 604 mm;
- pallet surface: S_p= 25.5 cm x 12.8 cm=326 cm^2
- thickness of the material layer in the mixer: h_m = 310 mm;

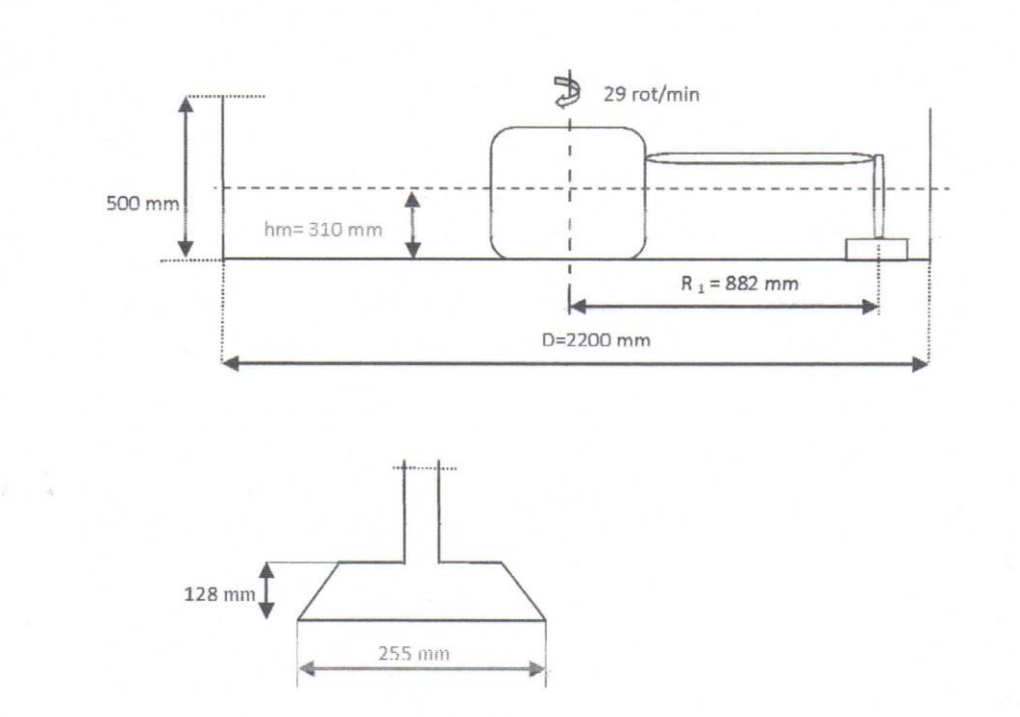


Figure 4.1- The scheme of vertical axis mixer BAF 750 l

Calculation of bending masses for TEKA BAF 750 l mixer

Bending mass: $M_1 = m_p + m_b + m_1 + m_2$ (4.1),

in which:

-m_p is the pallet mass;

- m_b is the mass of the arm portion inserted into the material;
- m_1 represents the concrete mass in front of the pallet, during the mixing process;
- m_2 represents the concrete mass in front of the pallet arm, during the mixing process.

$m_p = q_m \text{x } S_p \text{x } g_p$, (4.2)

and considering: the pallet thickness g_p= 1.71 cm , q_m=7.85 kg/dm^3, it results m_p= 4.38 kg;

$m_b = (h_m - h_p) \text{x } \frac{\pi d^2}{4} \text{x } q_m$ (4.3)

$m_b = (31\text{-}12.8) \text{x} \frac{\pi\ 3{,}2^2}{4} \text{x} 10^{-3} \text{ x } 7.85 = 1.148$ kg

m_1= S_px q_bx 2 π x R_1 (at the pallet number 1) (4.4)

m_1 = 0.0326 x 2200x 6.28 x 0.882 = 397.25 kg,

in which q_b is the fresh concrete density, considered to have the value of 2200 kg/m^3

m_2= (h_m-h_p)x $\frac{\pi d}{2}$x 2π R_1 xq_b (4.5)

It results m_2= 111.42 kg;

Applying the relation (4.1) we obtain**:** $\boldsymbol{M_1}$**=514.2 kg.**

For the palett number 2, arranged at radius R_2= 814 mm, with the same mass m_p = 4.38 kg and the same value for m_b we obtain:

m_1= S_px q_bx 2 π x R_2= 0.0326 x 6.28 x x 0.814 x 2200= 366.62 kg

m_2= (h_m-h_p)x $\frac{\pi d}{2}$x 2π R_2 xq_b=102.83 kg

From relation (4.1) it results: M_2 = 474.97 kg

Using the same calculation formulas, for the other mixer pallets it obtains the values:

M_3 = 470.97 kg; M_4 = 426.54 kg; M_5 = 394.8 kg; M_6 = 353.8 kg.

The excitation pulsation (rotor pulsation) for the TEKA BAF 750 l mixer is:

$\omega_r = \frac{\pi n_r}{30} = \frac{3.14\ x\ 29}{30}$ = 3.03 rad/s (4.6)

IV.2 Case of the TEKA 1500 l mixer. Calculation of the own pallets pulsations and of the movement amplitudes[20]

Calculation of bending masses for TEKA BAF 1500 l mixer

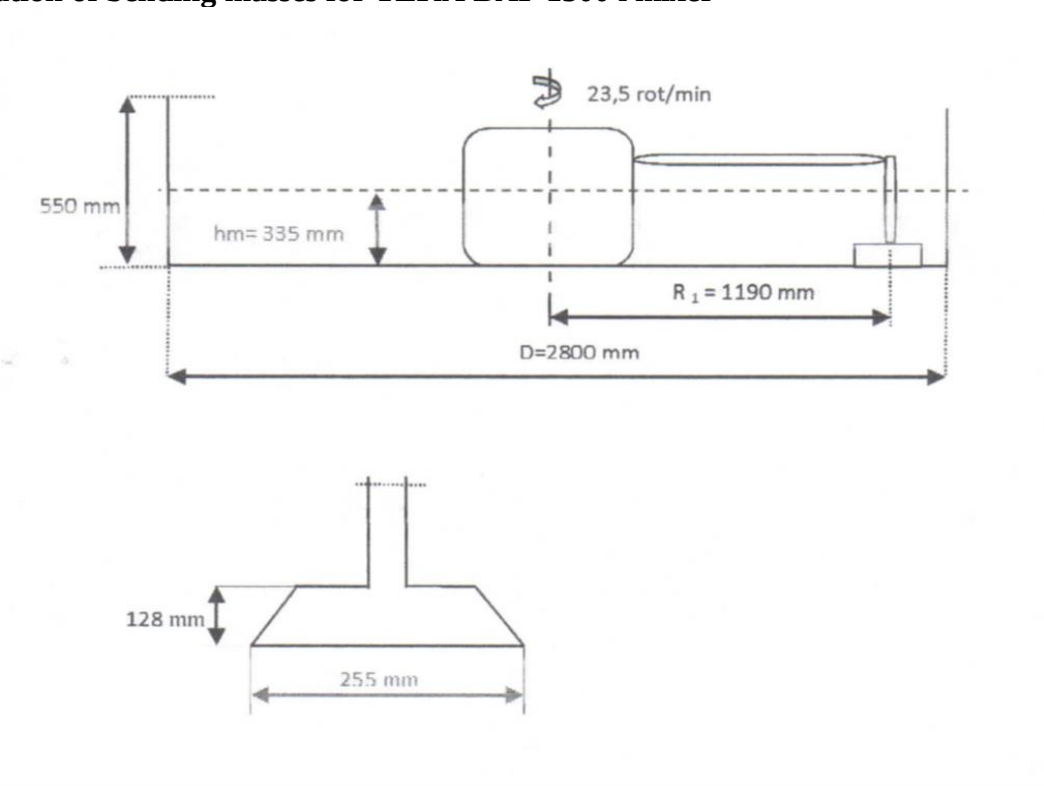


Figure 4.2- The scheme of vertical axis mixer BAF 1500 l

Figure 4.2. Schematic representation of the TEKA BAF 1500 l mixer, with a useful capacity of 1.0 m^3, having the following technical characteristics: productivity 50-60 m^3/h, motor power 37 kW, rotor speed 23.5 rpm, number of pallets: 6 pieces [13].

Technological and dimensional characteristics for the TEKA mixer shown in figure 4.2:

- diameter of the mixer arm d = 38 mm,

- axial resistance modulus $I_z = \frac{\pi d^4}{64} = 10.23 \text{ x}10^4\ mm^4$
- pallets radiuses: R_1= 1190 mm; R_2= 1142 mm; R_3= 1070 mm;
  R_4= 958 mm; R_5= 879 mm; R_6= 764 mm;
- pallet surface: S_p= 25.5 cm x 12.8 cm=326 cm^2
- thickness of the material layer in the mixer: h_m = 335 mm;

By applying formulas 4.1-4.6 for the TEKA BAF 1500 l mixer, the following values of the bending masses for the mixer pallets 1- 6 are obtained:

M_1=746.43 kg; M_2= 716.62 kg; M_3= 671.91 kg;

M_4= 602.71 kg; M_5=553.29 kg; M_6=481.86 kg.

System excitation pulsation (rotor pulsation) for TEKA BAF 1500 l mixer:

$\omega_r = \frac{\pi n_r}{30} = \frac{3.14\ x\ 23,5}{30}$ = 2.45 rad/s

Calculation of angular deformation and maximum arrow [5,6,7]

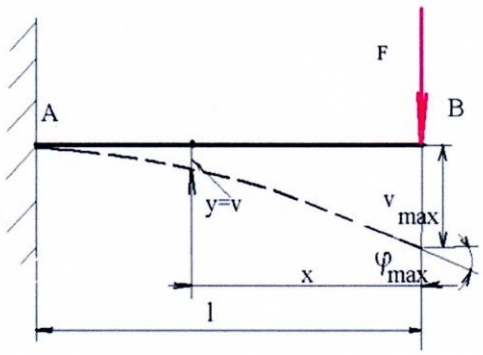


Figure 4.3- Mixer arm scheme, presented like an embedded beam

The arm-pallet system is considered as an embedded beam of length l, subjected to the force F action produced by the bending masses (figure 4.3), for which the maximum angular deformation and the maximum arrow are determined by applying the following equations:

$EI_z \frac{df}{dx} = EI_x \varphi = \int Fxdx + C_1 = \frac{Fx^2}{2} + C_1$ (4.7)

The integration constant is determined from boundary condition x=l, φ=0

$0 = \frac{Fl^2}{2} + C_1$, deci $C_1 = -\frac{Fl^2}{2}$

$\varphi = \frac{1}{EI_z}(\frac{Fx^2}{2} - \frac{Fl^2}{2})$ (4.8)

Maximum angular deformation occurs in the embedding, for x=0:

$\varphi_{max} = \frac{Fl^2}{2EI_z}$ [5,6,7] (4.9)

Maximum arrow calculation

$EI_z v = \int (\frac{Fx^2}{2} - \frac{Fl^2}{2})\ dx + C_2 = \frac{Fx^3}{6} - \frac{Fl^2 x}{2} + C_2$ (4.10)

The integration constant is determined from boundary condition x=l, ν=0

$0 = \frac{Fl^3}{6} - \frac{Fl^2}{2} + C_2$, that is it results $C_2 = \frac{Fl^3}{3}$

$v = \frac{1}{EI_z}(\frac{Fx^3}{6} - \frac{Fl^2 x}{2} + \frac{Fl^3}{3})$ (4.11)

The maximum arrow occurs at the free end, for x=0:

$v_{max} = f = \frac{Fl^3}{3EI_z}$ [5,6,7] (4.12)

The determination of pallets own pulsations, bending arrows and maximum movement amplitudes, graphical representation of amplitude variation in relation with the pulsation [20]

The maximum arm-pallet system arrow at each mixer:

$f = \frac{Fl^3}{3\,EI}$

Disturbing force: $F = F_0 \sin \omega t$; $F_0 = mg = kf$ [4] (4.13)

System elastic constant: $k = m\omega^2$ [4] (4.14)

$\omega = \sqrt{\frac{k}{m}}$, therefore from the relation 4.12 it results:

$\omega = \sqrt{\frac{g}{f}} = \sqrt{\frac{3EI}{ml^3}}$ [5] (4.15),

in which m is the total bending mass and l= R (the radius) for each pallet, E is the elasticity modulus of the steel E= 2.1 x 10^5 N/mm^2, and I=I_z is the axial resistance modulus

The amplitude calculation ratio is as follows:

$A_1 = \frac{F_{01}}{\sqrt{(k_1 - m_1\omega^2)^2 + c^2\omega^2}}$ [4] (4.16)

In which, for each pallet the forces F_{0i} =M_1g are given by the bending masses M_i.

Elastic constants for each pallet are given by the relation:

$k_i = \frac{3EI}{{R_i}^3}$ (4.17),

and c= $2\xi\sqrt{km}$ [4] (4.18),

in which ξ= 0.2 is the movement damping factor [5].

For the mixer TEKA BAF 750 l we obtain by applying the relation (4.15) the next values for the own pallet pulsations :

-at the pallet 1 (with the largest radius):

$\omega_1 = \sqrt{\frac{3x2.1x10^5x\ 5.14x10^4}{514.2\ x0.882^3x\ 10^9}x\ 10^3} = \sqrt{91.8}$ = 9.58 rad /s;

Similarly it is determined the own pulsations for the other pallets:

ω_2= 7.77 rad /s; ω_3= 8.82 rad/s; ω_4= 11.01 rad/s; ω_5= 13.09 rad/s; ω_6= 17.32 rad/s.

Maximum amplitudes obtained for the pallets of the two mixers

1)For the mixer TEKA BAF 750 l we obtain, after the use of relation (4.16):

A_1= 0.278 m , for pulsation value of ω= 9.18 rad/s;

A_2= 0.201 m for ω= 10.75 rad/s;

A_3= 0.195 m, for ω= 10.97 rad/s

A_4= 0.130 m, for ω= 13.36 rad/s;

A_5= 0.09 m, for ω= 15.68 rad/s;

A_6= 0.06 m, for ω= 19.53 rad/s.

For elastic constants it applies the relation (4.17) and we obtain the values: k_1= 47195 N/m; k_2=60038.5 N/m; k_3= 61614.5 N/m; k_4= 83240.5 N/m; k_5 =105291 N/m; k_6= 146957.8 N/m.

The movement amplitude graphical representation according to the pallets pulsation variation is given in figure 4.4, in which the motion damping mode is observed starting from the pallet 1 furthest from the rotor with the maximum amplitude of 0.278 m and up to the closest pallet (the sixth), with a maximum amplitude of only 0.06 m.

2) For TEKA BAF 1500 l mixer we obtain applying the relation (4.16):

A_1= 0.498 m, for pulsation value ω= 6.86 rad/s; A_2= 0.424 m, for ω= 7.46 rad/s;

A_3= 0.326 m, for ω = 8.48 rad/s; A_4= 0.210 m, for ω = 10.59 rad/s;

A_5= 0.148 m, for ω = 12.59 rad/s; A_6= 0.08 m, for ω = 16.58 rad/s.

For elastic constants it applies the relation (4.17) and we obtain the values: k_1= 38248.6 N/m; k_2=43283.4 N/m; k_3= 52611.4 N/m; k_4= 73302.6 N/m; k_5 =94896.3 N/m; k_6= 144522.7 N/m.

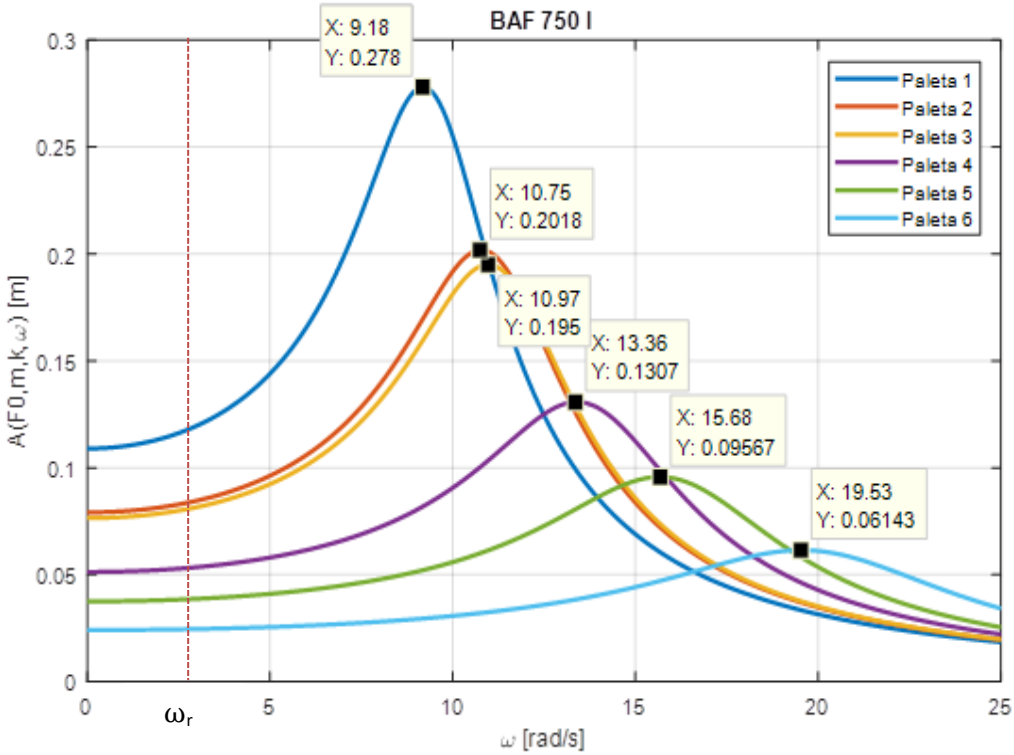


Figure 4.4-Amplitude-pulsation graphical reprezentation for the BAF 750 l pallets

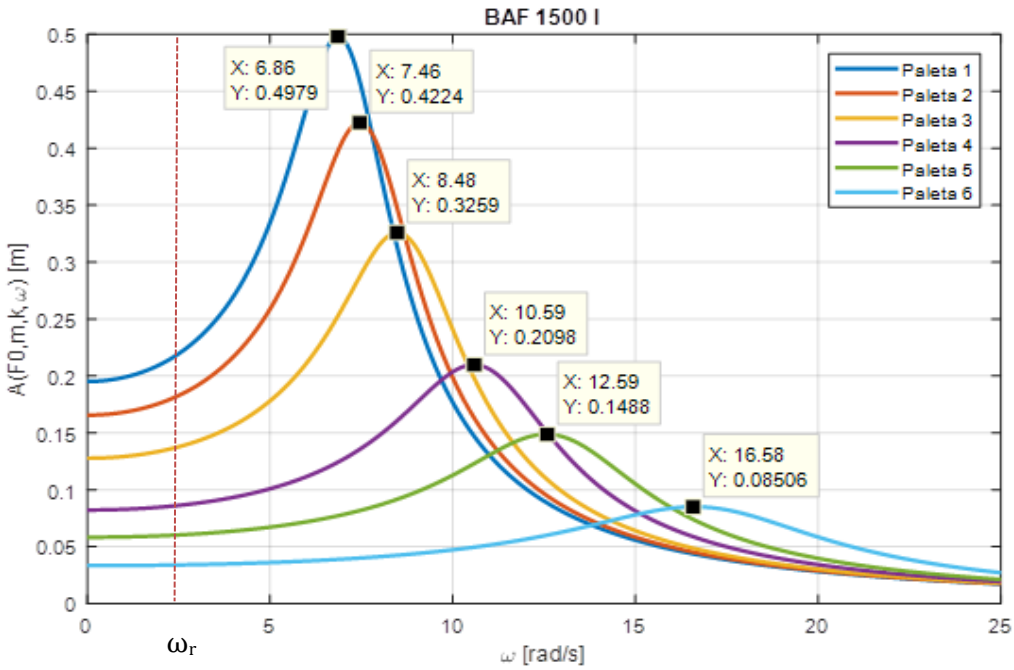


Figure 4.5-Amplitude-pulsation graphical reprezentation for the BAF 1500 l pallets

The movement amplitude graphical representation in relation with the pallets pulsation variation is given in figure 4.5, in which the motion damping mode is observed starting from the pallet 1 furthest from the rotor with the maximum amplitude of 0.498 m and up to the closest pallet (the sixth), with a maximum amplitude of only 0.08 m.

The graphs from Figures 4.4 and 4.5 also showed the pulsation of the rotor ω_r in order to highlight the values of the pallets amplitudes values when passing through this pulsation value. It is observed the decrease of the amplitudes with the pallets positions close to rotor, at

the same time the pulsations increase at values more and more distant from the excitation pulsation.

Conclusions:
From the analysis of the two graphs from figures 4.4 and 4.5 the following conclusions can be summarized:
- higher values of maximum amplitudes are obtained in the case of the TEKA BAF 1500 l mixer, due to the higher mixing volume, compared to TEKA BAF 750 l;
- the own pallets pulsations from the TEKA 750 l mixer are higher than those from the BAF 1500 l mixer, due to the lower values of the pallets arrangement radiuses;
- at the pallets of both mixers are obtained values of the own pulsations superior to the excitation pulsation;
- the system damping is more pronounced in the case of the smaller mixer due to the higher values of the elastic constants k, in relation to the TEKA BAF 1500 l mixer.

CHAPTER V

EXPERIMENTAL COMPARATIVE STUDY OF CUMULATIVE PARAMETERS DETERMINED ON A BATCH OF AUTOMATED CONCRETE STATIONS

Experiments were performed on a representative batch of ten automated concrete stations by measuring and determining the cumulative parameters. The ten concrete plants are in operation in various geographical areas from Romania, with different production capacities and various mixing systems: with a vertical axis (three cases analyzed), with two vertical axes (two cases) and with two horizontal axes (five cases).

The mixing times specified in the recipes in most cases (nine of ten) comply with the mixing time recommended by the manufacturers of those mixers. **At four of the concrete stations analyzed, the mixing times in the recipes exceeded the recommended values by 5-15 seconds.** In terms of parameters monitoring performance, two of the stations could not provide batch protocols, and those provided by four of the stations did not offer all the information about the actual mixing times.

Measurements and determinations were made during the concrete preparation of different strength and consistency classes, the most common concretes were C 12/15, C 16/20 and C 25/30 having consistency class S3, with the maximum aggregate granule of ϕ 16 mm.

The cumulative parameters measured were the following:
- the effective mixing time t_{mef}, measured with an electronic stopwatch shown in figure 5.1, from the moment when the last component was introduced in the mixer and the moment when the batch unloading started; the actual duration must be greater than or equal to the duration provided from the recipe;
- the cycle duration t_c, measured with the stopwatch shown in figure 5.1 between two successive loads of the mixer, used to verify the operational reliability of the concrete plant.

The cumulative parameters determined were the following:
- the components dosing errors, determined taking into account the actual dosing values read on display (in batch protocols- at eight of the analyzed stations) and the nominal values from laboratory recipe;
- the deviation of the water / cement ratio in relation to the value prescribed in the laboratory recipe;
- the speed of the shaft (s) with blades at the mixer, n, was determined in load-free operation, as a ratio between the number of rotations performed in a time period measured with the stopwatch shown in figure 5.1, and it must be within ± 5% of the value provided from the technical data manual.

To these parameters were added:

- the standard cycle duration t_{cn}, determined for the station technical productivity and the mixer useful capacity;
- functioning productivity as the last stations representative parameter was determined for the measured cycle time and the mixer operational capacity.

Figure 5.1 Stopwatch used for measurements

Table 5.1

Crt. no	t_{mref} (sec)	t_{cn} (sec)	t_{mef} (sec)	t_c (sec)	P_{th} (m^3/h)	P_{oper} (m^3/h)	Dosing errors according to CP 012/1-2007(%)	Actual dosing errors
1	30	84	33.4	98	96	82.6	± 3 aggreg., water, cement ± 5 additives	0.4 agregg; 0.2 cem; 0.25 water;1.24 addit.
2	30	60	36	72	60	50	± 3 aggreg., water, cement ± 5 additives	1.2 agregg; 0.66 cem; 0.78 water;1.12 addit.
3	30	60	30,2	74	60	48.6	± 3 aggreg., water, cement ± 5 additives	1.07 agregg; 0.33 cem; 1.16 water; 2.14 addit.
4	30	67.5	31	78.3	80	69	± 3 aggreg., water, cement ± 5 additives	0.96 agregg;0.24 cem; 0.38 water;0.76 addit.
5	40	90	42	109	80	66	± 3 aggreg., water, cement ± 5 additives	1.33 agregg; 0.58 cem; 0.79 water; 1.36 addit.
6	40	135	41	146.5	40	36.8	± 3 aggreg., water, cement ± 5 additives	0.94 agregg; 0.77 cem; 0.35 water; 1.23 addit.
7	45	82.6	50.3	88	98	82	± 3 aggreg., water, cement ± 5 additives	1.18 agregg; 0.42 cem; 0.59 water; 1.49 addit.
8	45	85	49.4	94	106	95.7	± 3 aggreg., water, cement ± 5 additives	0.64 agregg; 0.18 cem; 0.26 water; 1.94 addit.
9	45	108	46	122	50	36.9	± 3 aggreg., water, cement ± 5 additives	2.02 agregg; 0.98 cem; 0.52 water; 1.56 addit.
10	45	80	45.4	92	45	39.1	± 3 aggreg., water, cement ± 5 additives	1.55 agregg; 0.36 cem; 1.32 water; 2.66 addit.

Figures 5.2 to 5.4 show the following graphical representations:
- the mixing times graphical representation of the effective values and those provided in the laboratory recipes, during the concrete preparation for the ten concrete stations analyzed;
- the effective cycle times graphical representation, in relation to the values specified in the technical data manual, for the ten stations analyzed.

Table 5.1 presents the ten concrete stations at which the measurements / determinations were performed, as well as the values obtained for the cumulative parameters, to which was added the functioning productivity as an additional parameter.

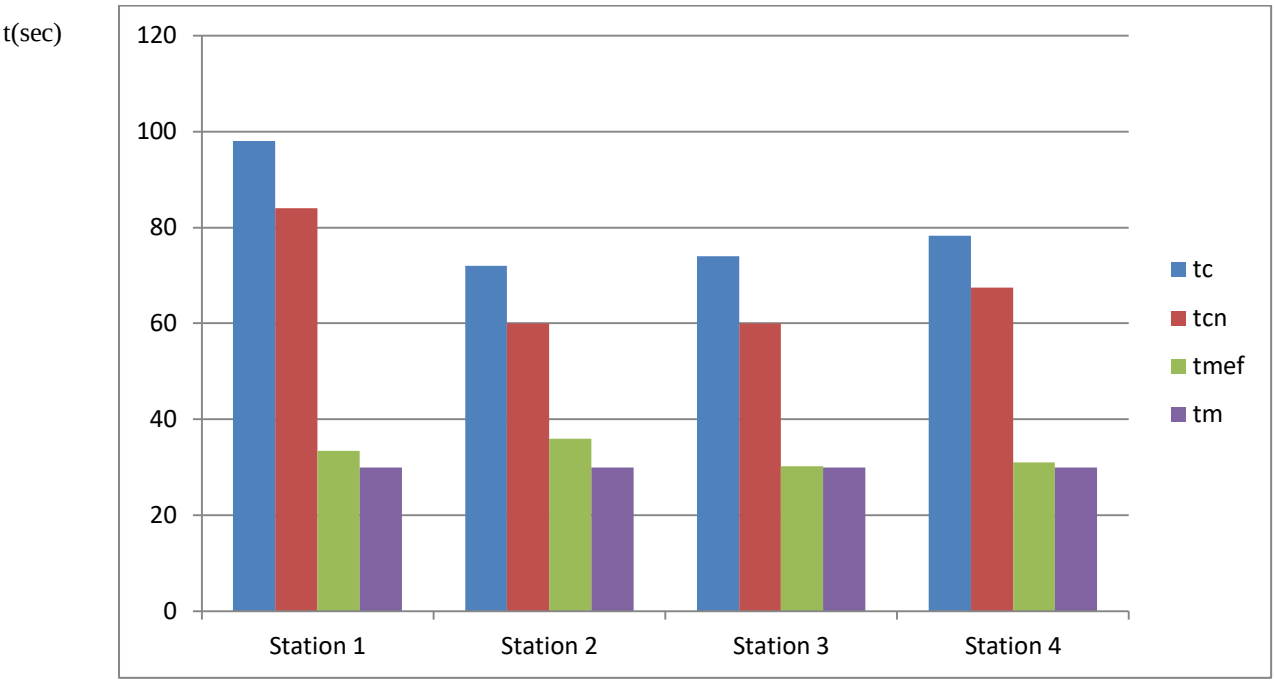


Figure 5.2 –Effective mixing time and cycle time values representation for the station 1-4

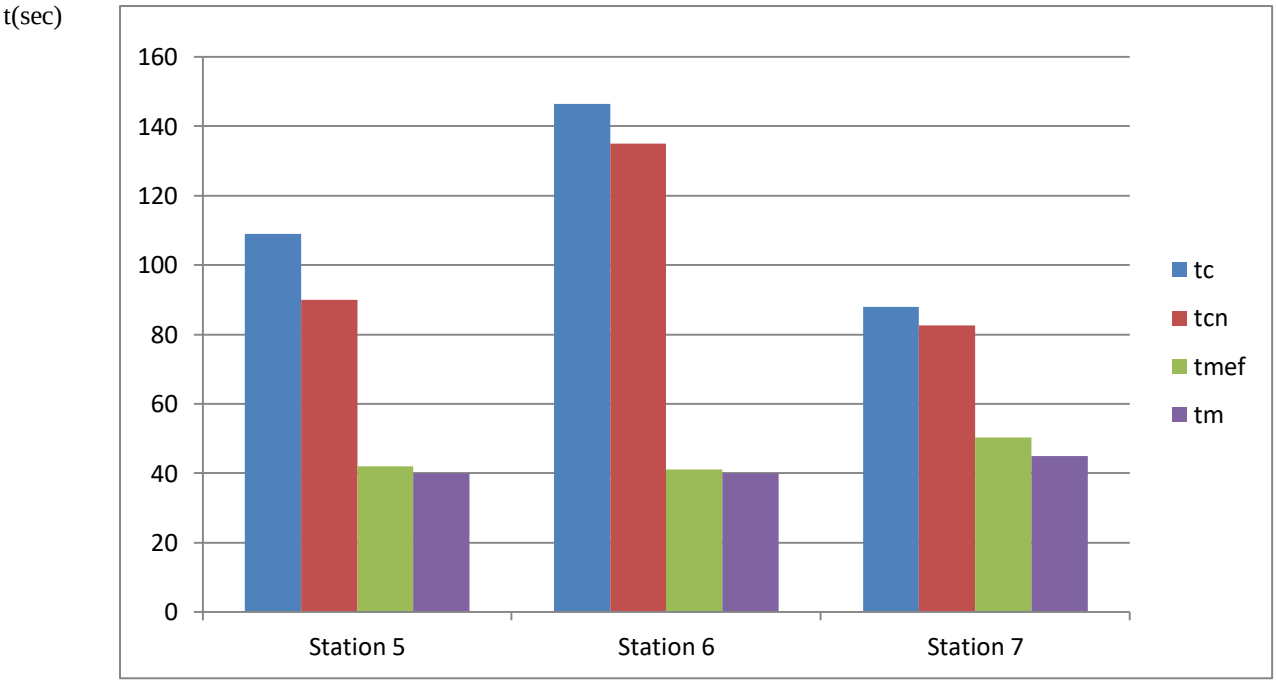


Figure 5.3 –Effective mixing time and cycle time values representation for the stations 5-7

Figures 5.5-5.6 represent graphically the dosing errors determined during the concrete preparation at the ten concrete stations analyzed.

The purpose of these graphical representations is revealed by the conclusions about the compliance with: the mixing times provided in the recipes, the dosing errors provided in CP 012/ 1-2007 and the concrete plants reliability, evaluated starting from the cycle time increase, due to the blockages and the wear, after a long period of operation.

In the table 5.2 have been presented the mixers speeds from the ten stations analyzed endowment, in form of values from the technical data manual and values determined in load-free operation regime.

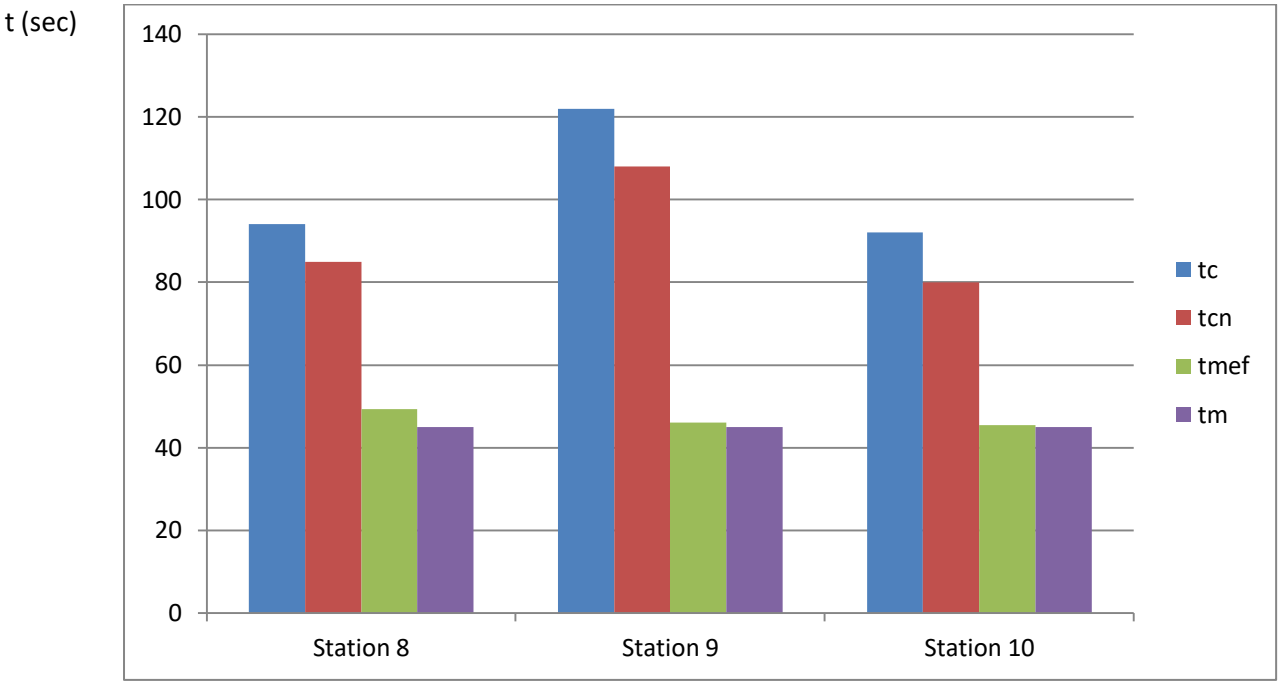


Figure 5.4 –Effective mixing time and cycle time values representation for the stations 8-10

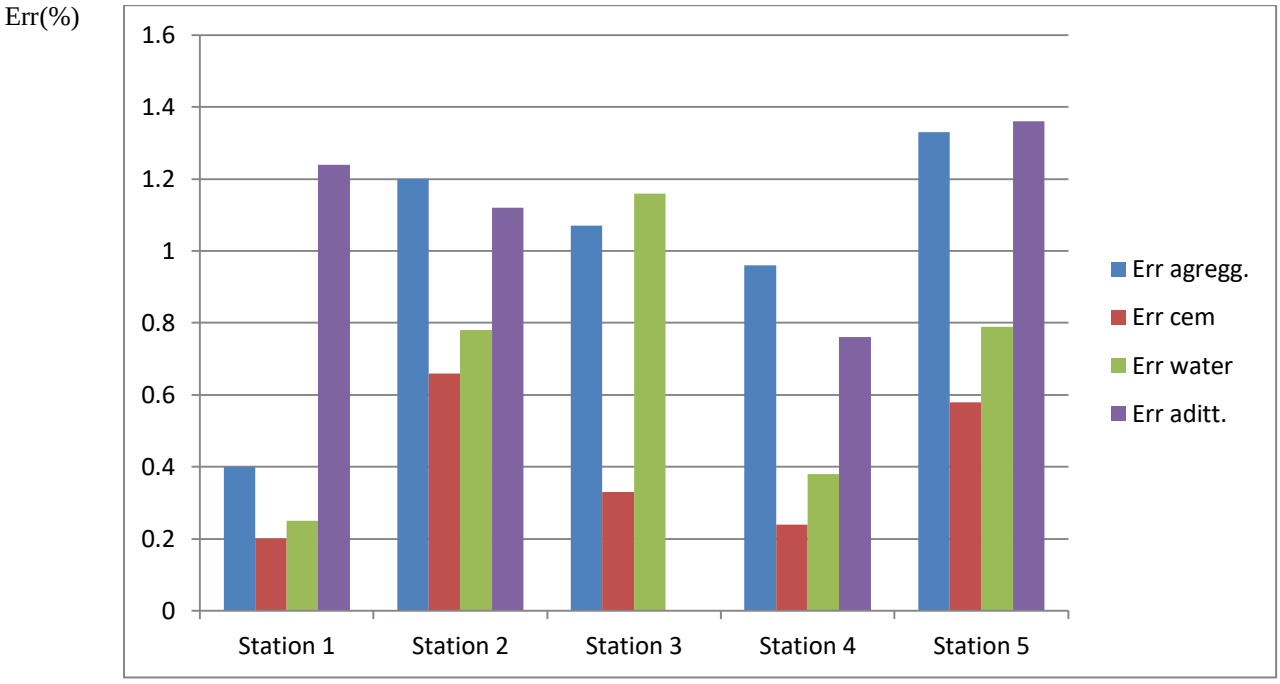


Figure 5.5- Actual dosing errors of components obtained for the stations 1-5

Table 5.2. Actual mixers speeds values determined for the ten concrete stations

Station	1	2	3	4	5	6	7	8	9	10
n_{CT} (rot/min)	20.7	26.4	45	25	30	30	20.7	20.7	25	25
n_{det} (rot/min)	20.26	24.72	43.94	23.14	29.88	30.23	19.62	20.24	24.16	25.19

Conclusions about the working mode of the analyzed stations

The comparison of the predicted values with the measured values for the mixing time and the cycle time (see the graphs from figures 5.2-5.4) leads to the following conclusions:

- the actual mixing time is longer than that prescribed in recipe for all stations, with clearer differences only in the case of the four stations that assess consistency automatically;

- the effective durations of the cycles are longer than those normed by 6-20 seconds;

The dosing errors determined and shown in the table 5.1 and in the graphs from figures 5.5 and 5.6 for all ten stations analyzed led to the following conclusions:

- the dosing errors were within the values provided by CP 012 / 1-2007 [10];
- the smallest errors were generally obtained at the cement dosing, and the largest at the additive dosing;
- water and cement dosing errors (less than 2%) give concrete plants the opportunity to comply with the 0.02 deviation imposed by CP 012 / 1-2007 for the water / cement ratio [10].

The determined speeds of the pallet shafts (table 5.2) were within ± 5%, compared to the values provided in the technical data manual at eight of the ten concrete plants from the group, being closer to them in the case of newer stations.

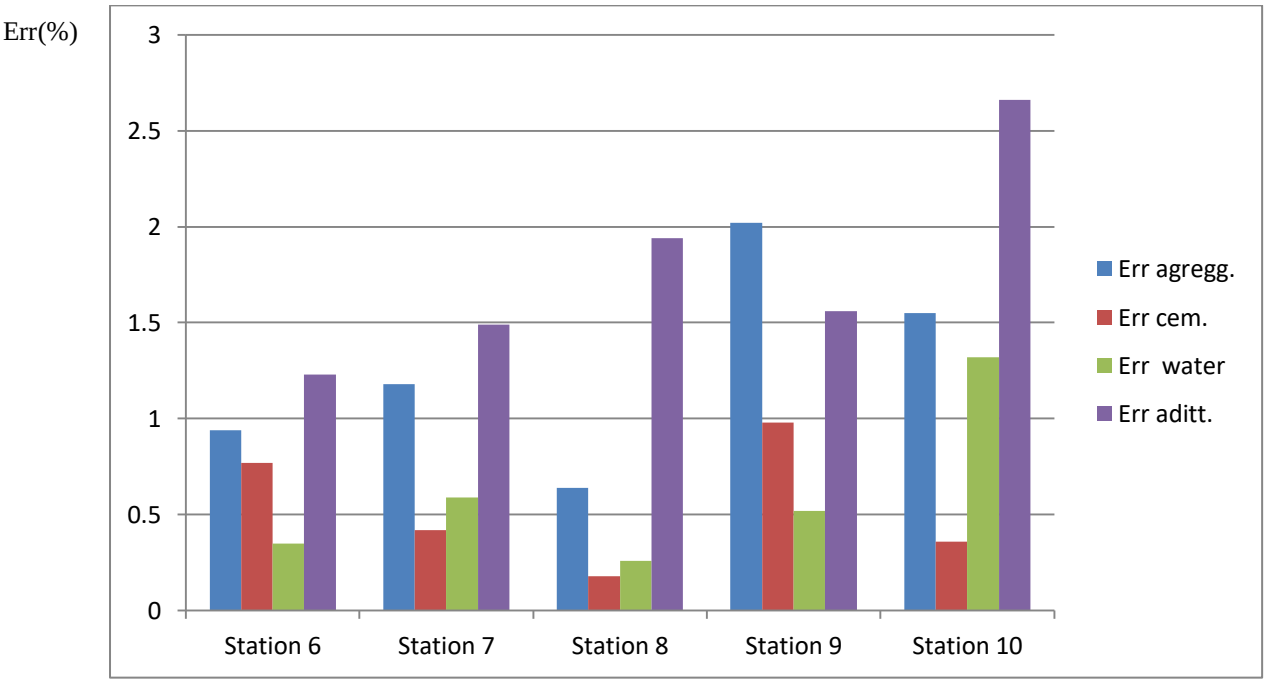


Figure 5.6 - Actual dosing errors of components obtained for the stations 6-10

CHAPTER VI

DETERMINATION OF THE RELATIONS BETWEEN MIXING TIME AND CONCRETE COMPRESSION STRENGTH FOR DIFFERENT MIXING SYSTEM

IV.1. Concrete mixing study, mixer factor determination

Two vertical axis mixer case

Calculation of the power required to operate each shaft with blades, using the relation:

$$P_m = M\omega, \quad [2] \qquad (6.1)$$

From which it results:

$$P_m = \frac{k_m n \sum r_{mi}(S_i cos\alpha_i cos\beta_i + A_{si})}{95500\ \eta_{tr}}\ [kW], \quad [2] \quad (6.2)$$

Relation from which it is determined k_m, as average specific mixing resistance. In relation (6.2) we have:

- n is the speed of the axis with pallets (rpm); η_{tr} is the efficiency of the mixer motor- pallets shaft transmission; S_i represents the pallets surface; α_i and β_i are the pallets inclination angles in vertical / horizontal plane; A_{Si} represents the area of the mixing arm portion located inside the material during mixing and it is determined by the relation:

$A_{si} = \frac{\pi d}{2}(h_m - h_p cos\beta i)[cm^2]$, [2] (6.3),

in which: d is the arm diameter; h_m the material layer height; h_p the pallet height.

The mixing resistance determination for n x 2 pallets (n pallets placed on each axis) is made considering the pallets average radius:

$r_{m1} = r_{m2} = \frac{1}{n}\sum r_i \ [cm]$ (6.4)

For each pallet it applies the relation :

$k_i = \frac{r_i}{r_m} k_m [daN/cm^2]$, (6.5)

The calculation of the pallets tangential speeds for each axis is made by applying the relation:

$v_i = \omega r_{ie} = \frac{\pi n}{30} r_{ie} [m/s]$ (6.6),

in which r_{ie} represents the outer radius (tangential) of each pallet

The case of the mixer with a vertical shaft with pallets, with or without agitator

In the case of the mixer with a vertical axis with pallets, the calculation relations from the mixer with two vertical axes are applied, with the difference that in relation (6.2) only the power necessary to operate the n pallets will be introduced (not the one necessary to operate the agitator).

Study of mixers with two horizontal axis

Calculating the power required to drive each pallets shaft, considered to be equal to the power of the drive motor, using relation (6.1), we obtain:

$P_m = \frac{\psi z n k_m b(r_e{}^2 - r_i{}^2)}{2x\, 95500 x \eta_{tr}} x\, cos\alpha [kW]$ [2] (6.8),

wherein: ψ = 0.6… 0.7 is the filling coefficient of the mixing trough; z is the total number of pallets; b is the pallet width; α is the pallets inclination angle with the longitudinal plane of the trough; r_e and r_i are the outer and inner radiuses of the pallets placed in a radial vertical plane; η_{tr} is the engine-mixer transmission efficiency; k_m is the average specific mixing resistance, equal to the mixing resistance for each pallet, because $r_i = r_m$.

Tangential speeds equal for the z pallets it is determined with relation (6.6), in which $r_{ie} = r_e$

Case studies – *exemples of mixing resistance and kneading speed calculation*

1. SICOMA mixer of 1.5 mc with two vertical axis, shown in figure 6.1, has the next technical specifications [14,19]: drive engines power 30+30 kW; pallets number 3+3; the two rotors speed 30+30 rot/min.

Considering: d = 5 cm, h_m = 46.6 cm, also h_p =12.8 cm, S_i= 332 m^2 , α_i=40^0 , β_i= 25^0 and the pallets radiuses on the two axis 62, 60 and 58 cm, by applying the relation (6.3) we obtain: A_{si}= 274 cm^2; $S_i cos\alpha_i cos\beta_i$= 230 cm^2; $\sum r_{mi}(S_i cos\alpha_i cos\beta_i + A_{si})$ = 90720 cm^3, for each mixer axis;

In relation (6.2), introducing drive engine power for one axis of 30 kW and $\eta_{tr} = 0.85$ it will result $\boldsymbol{k_m = 0.89\ daN/cm^2}$.

The tangential speeds for the three pallets, determined with relation (6.6) are the following:

v_1= 2.30 m/s; v_2= 2.22 m/s; v_3= 2.14 m/s.

2. SICOMA mixer of 1.5 mc with two horizontal axis, shown in figure 6.2, has the next technical specifications [14,19]: drive engine power of the two axis 55.2 kW; active pallets number 6+6= 12; axis speed 25 rot /min.

Introducing in relation (6.8) the values: ψ = 0.7, z =12, b = 28 cm, α = 40^0, r_e = 50 cm, r_i = 35 cm and η_{tr} =0.85, we obtain $\boldsymbol{k_m = 1.56\ daN/cm^2}$

Pallets tangential speed, resulted by applying relation (6.6) is: $\boldsymbol{v}$ **= 1.31 m/s.**

3. LIEBHERR mixer of de 2.25 mc with a vertical axis having 5 pallets and one agitator, shown in figure 6.3, has the next technical specifications [15,19]: engine power 90 kW; pallets drive power 70 kW; rotor speed 20.7 rot/min.

Considering: d = 5.2 cm, h_m = 51.8 cm, also h_p =12 cm, S_i= 336 cm^2, α_i=40^0, β_i= 25^0 and pallets radiuses: 142, 128, 114, 103 and 88 cm, by applying the relations we obtain:
A_{si}= 325 cm^2; $S_i cos\alpha_i cos\beta_i$= 233 cm^2; $\sum r_{mi}(S_i cos\alpha_i cos\beta_i + A_{si})$= 320850 cm^3, for the five pallets mixer;
In relation (6.2), introducing drive engine power fot the five pallets of 70 kW and $\eta_{tr} = 0{,}85$ it will result: $\boldsymbol{k_m = 0.86\ daN/cm^2}$**.** Maximum speed at pallet 1**:** $\boldsymbol{v_1}$**= 3.08 m/s** .

Figure 6.1- SICOMA mixer with two vertical axis of 1.5 mc capacity

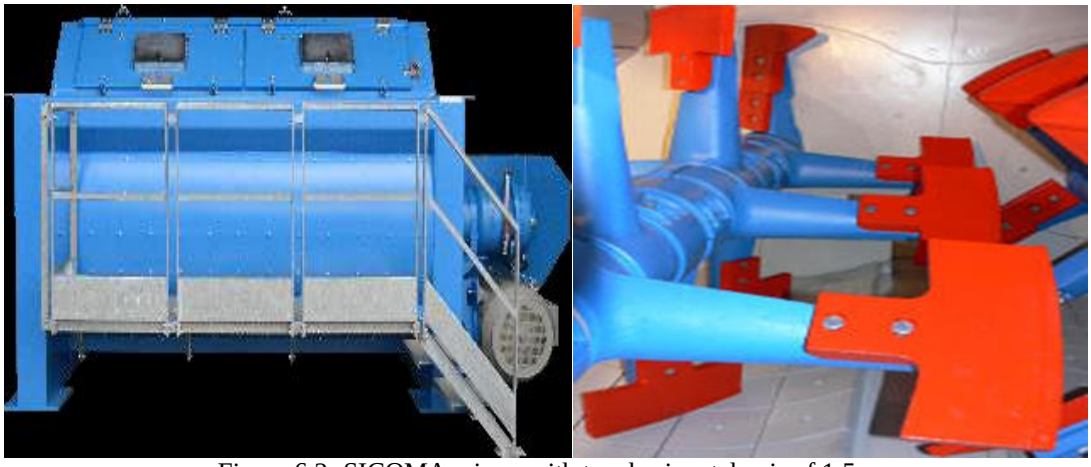


Figure 6.2- SICOMA mixer with two horizontal axis of 1.5 mc

4. LIEBHERR mixer of 2.25 mc with two horizontal axis, shown in figure 6.4 have the following technical specifications [15,19]: the installed power 75 kW; pallets number 6 x 2=12; pallets drive power 70 kW**;** rotor speed 20.7 rot/min;
Introducing in relation (6.8) the values: ψ = 0.7, z =12 , b = 28 cm, α = 40^0, r_e = 57 cm, r_i = 42 cm and η_{tr} = 0.85 we obtain: $\boldsymbol{k_m = 2.05\ daN/cm^2}$
Pallets peripheral speed: $\boldsymbol{v}$ **= 1,3 m/s.**
Similarly were determined peripheral speeds and mixing resistance for [14]:
- the SICOMA mixer with two horizontal axis, with 1.0 mc capacity, engine power 37 kW, rotor speed 25 rot/min, pallets number 8 pieces [20]; **v = 1.17 m/s**, $\boldsymbol{k_m}$**= 1.47** $\boldsymbol{daN/cm^2}$;
- the SICOMA mixer with two horizontal axis with 2.0 mc capacity, engines power 2x37 kW, speed 25 rot/min, 12 pallets [20]; **v = 1.30 m/s**, $\boldsymbol{k_m}$**= 1.78** $\boldsymbol{daN/cm^2}$.
In the same way for the SICOMA mixers with two vertical axis it is determined[14]:

- for mixer of 1.0 mc capacity (engine power 45 kW, rotor speed 45 rot/min, 6 pallets): **v = 2.58 m/s**, $\boldsymbol{k_m}$**= 0.61** $\boldsymbol{daN/cm^2}$**;**
- for mixer of 2.0 mc capacity (engines power 2 x 45 kW, rotors speed 30 rot/min, 6 pallets) : **v = 2.60 m/s**, $\boldsymbol{k_m}$**= 0.81** $\boldsymbol{daN/cm^2}$**.**

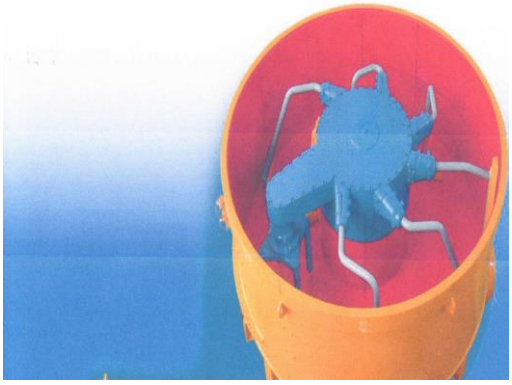


Figure 6.3- LIEBHERR mixer of 2.25 mc

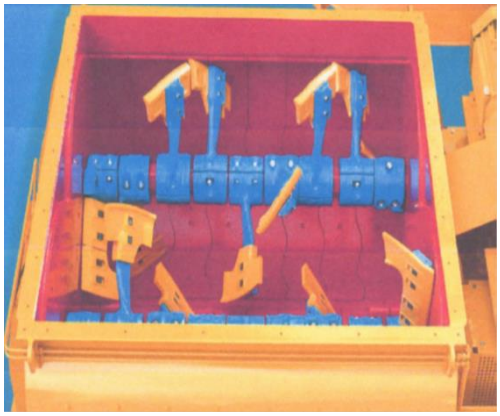


Figure 6.4 – LIEBHERR mixer of 2.25 mc

Using the relations 6.2 and 6.6 for the mixers with a vertical axis it is determined [15]:
- for the LIEBHERR mixer with a vertical axis of 0.5 mc, (engine power 22 kW, rotor speed 26.2 rot/min, 5 pallets) : **v = 2.38 m/s,** $\boldsymbol{k_m}$**= 0.44** $\boldsymbol{daN/cm^2}$**;**
- for the LIEBHERR mixer with a vertical axis of 1.0 mc, (engine power 37 kW, rotor speed 26.4 rot/min, 5 pallets) : **v = 2.75 m/s,** $\boldsymbol{k_m}$**= 0.54** $\boldsymbol{daN/cm^2}$**;**
- for the LIEBHERR mixer with a vertical axis of 2.0 mc (engine power 75 kW, rotor speed 20.7 rot/min, 5 pallets + agitator) : **v = 2.80 m/s,** $\boldsymbol{k_m}$**= 0.78** $\boldsymbol{daN/cm^2}$**.**

Mixer factor it is determened for each mixer separately like multiplication of three factors:
- **resistance factor** $\boldsymbol{k_{rez}}$, like ratio between the mixing resistance of the respective mixer and a resistance considered maximum for respective mixing system;
- **speed factor** $\boldsymbol{k_{vit}}$, calculated like difference between the speed considered optimal and the average kneading speed for the respective mixer, reported to a reference speed (1.0 m/s);
- mixer **filling factor** with material $\boldsymbol{k_u}$, like a ratio between operational capacity (of the concrete batch) and mixer useful capacity.

$f_m = k_{rez} \text{ x } k_{vit} \text{ x } k_u$ (6.9)

The mixer factor determination for different capacities and mixing systems

Mixers with a vertical axis

1) Useful capacity of 0.5 mc

$$\boldsymbol{k_{rez}} = \frac{\boldsymbol{k_{sp}}}{\boldsymbol{k_{max}}} = \frac{\boldsymbol{0.44}}{\boldsymbol{1{,}0}} = 0.44$$

$$\boldsymbol{k_{vit}} = \frac{\boldsymbol{v_o - v_m}}{\boldsymbol{v_{ref}}} = \frac{\boldsymbol{3-2.4}}{\boldsymbol{1}} = 0.6$$

k_u= 0.75, filling factor, available for all cases

It results applying the relation 6.9 **:** $\boldsymbol{f_m}$**=0.19**

2) Useful capacity of 1.0 mc:

$$k_{rez} = \frac{k_{sp}}{k_{max}} = \frac{0.54}{1{,}0} = 0.54$$

$$k_{vit} = \frac{v_o - v_m}{v_{ref}} = \frac{3-2.7}{1} = 0.3$$

it results: $\boldsymbol{f_m}$**=0.12**

3) Useful capacity of 2.0 mc:

$$k_{rez} = \frac{k_{sp}}{k_{max}} = \frac{0.80}{1.0} = 0.80$$

$k_{vit}=\frac{v_o-v_m}{v_{ref}}=\frac{3-2.8}{1}=0.2$,

it results: $\boldsymbol{f_m}$**= 0.12**

Mixers with two vertical axis

1) Useful capacity of 1.0 mc**:**

$\boldsymbol{k_{rez}}=\frac{\boldsymbol{k_{sp}}}{\boldsymbol{k_{max}}}=\frac{\mathbf{0.61}}{\mathbf{1.0}}=0.61$

$\boldsymbol{k_{vit}}=\frac{\boldsymbol{v_o-v_m}}{\boldsymbol{v_{ref}}}=\frac{\mathbf{2.8-2.58}}{\mathbf{1}}=0.22$

k_u= 0.75, filling factor, available for all cases

It results**:** $\boldsymbol{f_m}$**= 0.10**

2) Useful capacity of 1.5 mc:

$k_{rez}=\frac{k_{sp}}{k_{max}}=\frac{0.89}{1.0}=0.89$

$k_{vit}=\frac{v_o-v_m}{v_{ref}}=\frac{2.8-2.22}{1}=0.58$,

3) Useful capacity of 2.0 mc:

$k_{rez}=\frac{k_{sp}}{k_{max}}=\frac{0.81}{1.0}=0.81$

$k_{vit}=\frac{v_o-v_m}{v_{ref}}=\frac{2.8-2.6}{1}=0.2$,

It results: $\boldsymbol{f_m}$**=0.12**

Mixers with two horizontal axis

1) Useful capacity of 1.0 mc:

$\boldsymbol{k_{rez}}=\frac{\boldsymbol{k_{sp}}}{\boldsymbol{k_{max}}}=\frac{\mathbf{1.47}}{\mathbf{2,0}}=0.73$

$\boldsymbol{k_{vit}}=\frac{\boldsymbol{v_o-v_m}}{\boldsymbol{v_{ref}}}=\frac{\mathbf{1.5-1.17}}{\mathbf{1}}=0.33$

k_u= 0.75, filling factor, available for all cases

It results**:** $\boldsymbol{f_m}$**=0.18**

2) Useful capacity of 1.5 mc:

$k_{rez}=\frac{k_{sp}}{k_{max}}=\frac{1.56}{2.0}=0.78$

$k_{vit}=\frac{v_o-v_m}{v_{ref}}=\frac{1.5-1.17}{1}=0.33$

It results: $\boldsymbol{f_m}$**=0,19**

3) Useful capacity of 2.0 mc:

$k_{rez}=\frac{k_{sp}}{k_{max}}=\frac{1,78}{2,0}=0.89$

$k_{vit}=\frac{v_o-v_m}{v_{ref}}=\frac{1,5-1,3}{1}=0.2$

It results: $\boldsymbol{f_m}$**=0.13**

Recipe factor determination

When determining the recipe factor, the two most influential factors will be taken into account: the actual density of the prepared mixture and the actual water / cement ratio. The prescription factor is determined in two variants, with relation 6.10 or with relation 6.11.

$f_{r2}=1-\frac{\rho_{x-1}}{\rho_x}\ x\ \frac{a_x/c_x}{a_{x-1}/c_{x-1}}$ (6.10)

or: $f_{r1}=1-\frac{\rho_0}{\rho_x}x\frac{a_x/c_x}{a_0/c_0}$ (6.11)

in which:

- ρ_x ρ_{x-1}, and ρ_0 represent the densities of the mixture resulting from the concrete preparation of class x, x-1 (previous class) and zero class (considered C8/10) after the components dosing;

- a_x/c_x, a_{x-1}/c_{x-1} and a_0/c_0 represent the water / cement ratios resulting from the concrete preparation of class x, x-1 (previous class) and zero class, after the components dosing.

Case study

It is considered the case of C 8/10- C50/60 concrete preparation, it is determined the recipe factor in both versions, after the components dosing.

For strength class C8/10 of a concrete with consistency class S3 it is considered :

a/c= 0.72 and $\boldsymbol{\rho_{C8/10}}$ = $\boldsymbol{\rho_{x-1}}$ = 2345 kg/mc;

Applying relation (6.10) we find the next values for the recipe factor:

- for strength class C12/15, a/c= 0,68 and $\boldsymbol{\rho_x}$= 2348 kg/mc; it results $\boldsymbol{f_{r2}}$= 0.056;
- for C 16/20, a/c=0.64 and $\boldsymbol{\rho_x}$= 2355 kg/mc; $\boldsymbol{f_{r2}}$=0.061
- for C 18/22.5, a/c=0.60 and $\boldsymbol{\rho_x}$= 2353 kg/mc; $\boldsymbol{f_{r2}}$=0.061
- for C 20/25, a/c=0.56 and $\boldsymbol{\rho_x}$= 2359 kg/mc; $\boldsymbol{f_{r2}}$=0.085
- for C 25/30, a/c=0.51 and $\boldsymbol{\rho_x}$= 2355kg/mc; $\boldsymbol{f_{r2}}$=0.087
- for C 30/37, a/c=0.47 and $\boldsymbol{\rho_x}$= 2371kg/mc; $\boldsymbol{f_{r2}}$=0.085
- for C 32/40, a/c=0.44 and $\boldsymbol{\rho_x}$= 2376 kg/mc; $\boldsymbol{f_{r2}}$=0.066
- for C 35/45, a/c=0.41 and $\boldsymbol{\rho_x}$= 2379 kg/mc; $\boldsymbol{f_{r2}}$=0.069
- for C 40/50, a/c=0.39 and $\boldsymbol{\rho_x}$= 2388 kg/mc; $\boldsymbol{f_{r2}}$=0.052
- for C 50/60, a/c=0.36 and $\boldsymbol{\rho_x}$= 2398 kg/mc; $\boldsymbol{f_{r2}}$=0.080

Applying relation (6.11) we find the next values for the recipe factor:

- for C12/15, a/c= 0.68 and $\boldsymbol{\rho_x}$= 2348 kg/mc; rezultă $\boldsymbol{f_{r1}}$= 0.056
- for C 16/20, a/c=0.64 and $\boldsymbol{\rho_x}$= 2355 kg/mc; $\boldsymbol{f_{r1}}$=0.114
- for C 18/22,5, a/c=0.60 and $\boldsymbol{\rho_x}$= 2353 kg/mc; $\boldsymbol{f_{r1}}$=0.169
- for C 20/25, a/c=0.56 and $\boldsymbol{\rho_x}$= 2359 kg/mc; $\boldsymbol{f_{r1}}$=0.226
- for C 25/30, a/c=0.51 and $\boldsymbol{\rho_x}$= 2355kg/mc; $\boldsymbol{f_{r1}}$=0.294
- for C 30/37, a/c=0.47 and $\boldsymbol{\rho_x}$= 2371kg/mc; $\boldsymbol{f_{r1}}$=0.354
- for C 32/40, a/c=0.44 and $\boldsymbol{\rho_x}$= 2376 kg/mc; $\boldsymbol{f_{r1}}$=0.396
- for C 35/45, a/c=0.41 and $\boldsymbol{\rho_x}$= 2379 kg/mc; $\boldsymbol{f_{r1}}$=0.438
- for C 40/50, a/c=0.39 and $\boldsymbol{\rho_x}$= 2388 kg/mc; $\boldsymbol{f_{r1}}$=0.468
- for C 50/60, a/c=0.36 and $\boldsymbol{\rho_x}$= 2398 kg/mc; $\boldsymbol{f_{r1}}$=0.511

In figure 6.5 the values obtained for the recipe factor in the two variants are represented graphically, in order to highlight its variation mode with the concrete strength class.

Relationship between mixing time and compressive strength

A relationship of the following form is proposed between the mixing time and the compressive strength:

$$t_m = t_0 k_1 + t_0 k_2 \left(1 - \frac{R_{c0}}{R_c}\right) \quad (6.12),$$

where: t_0 is the mixing time specified in the recipe; k_1 is a factor that depends on the preparation conditions, k_1 can have values between 1.1-1.5; k_2 is a cumulative factor that includes the mixing factor and the recipe factor:

$$k_2 = f_m + f_r \qquad (6.13)$$

- R_{c0}=10 N/mm^2, minimum compressive strength for strength class C 8/10

CASE STUDIES. Relation 6.12 applies to different concretes, prepared in mixers with different capacities and mixing systems, for which the mixing times were measured with the stopwatch shown in figure 5.1 and the compressive strengths at 28 days were determined in the testing laboratories which served the respective concrete stations.

a) The case of mixers with a vertical axis

For a LIEBHERR mixer with useful capacity of 0.5 mc

It is considered the case of a prepared concrete of strength class C 16/20, having the value determined in the laboratory for compressive strength at 28 day R_c = 24.4 N/mm^2

In relation t_m=$t_0 k_1$+$t_0 k_2 \left(1 - \frac{R_{c0}}{R_c}\right)$, are introduced the next values:

t_0=30 sec, initial mixing time specified in recipe;

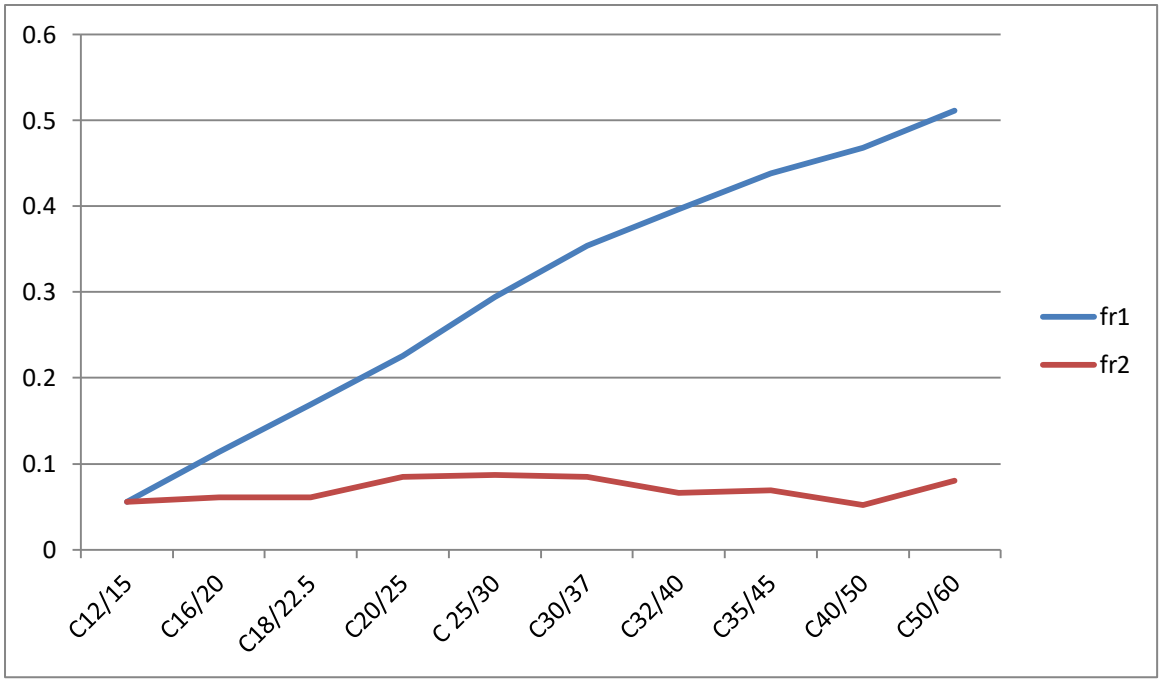


Figure 6.5- Variation of recipe factor determined in the variants f_{r1} și f_{r2}, with conctrete strength class

k_1=1 (normal conditions of fluid concrete preparation)

Calculated values for mixing time, in two variants:

t_{m1}= 30+ 30(0.19+ 0.114) (1 - $\frac{10}{24.4}$) = 35.4 sec, taking into account by the mixer factor and by the recipe factor calculated with relation (6.11)

t_{m2}= 30+ 30 x 0.061 (1 - $\frac{10}{24.4}$) = 31 sec, taking into account only by the recipe factor calculated with relation (6.10)

Measured value with stopwatch: t_{mas} =30.68 sec

Recommended mixing time: t_{mr}= 30 sec; in this case it is observed that $\boldsymbol{t_{mr} = t_0}$

For a LIEBHERR mixer of 1.0 mc, it was determined the next values:

- for C 12/15, R_c = 18.4 N/mm^2; for C 16/20, R_c = 28.9 N/mm^2; for C 20/25, R_c= 32.9 N/mm^2; for C 25/30, R_c = 38.7 N/mm^2; for C 30/37, R_c = 48.7 N/mm^2; for C 35/45, R_c= 52.7N/mm^2.

$\boldsymbol{t_{mr} = t_0}$ = 30 sec;

- for normal preparation conditions: k_1=1

Calculated values for t_{m1} (sec): 32.4; 34.5; 37.2; 39.2; 41.2; 43.5, taking into account by the mixer factor, f_m = 0.12 and the recipe factor calculated with relation (6.11).

Calculated values for t_{m2} (sec): 30.8; 31.2; 31.8; 31.9; 32.02; 33.1, taking into account only by the recipe factor calculated with relation (6.10).

Measured values with stopwatch: t_{mas} (sec): 30.15; 30.42; 31.25; 31.51; 31.67; 32.03

For a FRUMECAR mixer of 1.0 mc, at which mixing time from recipe was changed with the compressive strength it was determined the values:

- for C12/15, R_c = 23.8 N/mm^2,

t_0=35 sec, k_1=1; t_{m1}= 38.6 sec; t_{m2}= 36.1 sec; t_{mas}= 35.72 sec

-for C 18/22.5, R_c = 30.4 N/mm^2;

t_0=40 sec, k_1=1; t_{m1}= 47.7 sec; t_{m2}= 41.6 sec; t_{mas} = 40.52 sec

-for C 20/25, R_c = 35.4 N/mm^2

t_0= 45 sec, k_1=1; t_{m1}= 56.2 sec; t_{m2}= 47.7 sec; t_{mas} = 46.12 sec

t_{mr} = 30 sec; In this example we have $\boldsymbol{t_0} > \boldsymbol{t_{mr}}$, case rarely encountered in practice.

For LIEBHERR mixer with capacity of 2.0 mc :for C 25/30**,** R_c = 36.0 N/mm^2

t_0=30 sec, k_1=1

Determened values: t_{m1}= 38.9 sec; t_{m2}= 31.8 sec. Measured value: t_{mas} =32.77 sec

t_{mr} recommended by the mixer manufacturer = 30 sec ; $\boldsymbol{t_{mr}} = \boldsymbol{t_0}$

b)Mixers with two vertical axis

OCMER mixer with useful capacity of 1.0 mc: for C16/20**,** R_c = 23.8 N/mm^2**;**

for C 20/25, R_c =29.0 N/mm^2; for C 25/30, R_c = 36.8 N/mm^2

t_0=30 sec, k_1=1

t_{mr} recommended by the mixer manufacturer 40 sec; it is observed in this case that $\boldsymbol{t_0} < \boldsymbol{t_{mr}}$

Calculated values: t_{m1}= 33.7 sec; 36.4 sec; 38.6 sec.

t_{m2}= 31.06 sec; 31.7 sec; 31.9 sec.

Measured values t_{mas}: 30.47 sec; 30.51 sec; 31.02 sec.

SICOMA mixer with useful capacity of 1.5 mc: for C16/20**,** R_c= 29.9 N/mm^2**;** for C 20/25, R_c = 33.4 N/mm^2; for C 25/30, R_c = 41.8 N/mm^2

t_0=40 sec, k_1=1

Calculated values: t_{m1}= 53.04 sec; 56.9 sec; 60.48 sec.

t_{m2}= 41.6 sec; 42.4 sec; 42.6 sec.

Measured values: t_{mas}= 40.67 sec; 41.25 sec; 41.53 sec.

$\boldsymbol{t_{mr}} = \boldsymbol{t_0}$= 40 sec

SICOMA mixer of 2.0 mc capacity: for C 12/15, R_c = 19.2 N/mm^2**;**

for C18/22,5, R_c = 27.2 N/mm^2; pentru C 30/37, R_c = 41.6 N/mm^2.

t_0=30 sec, k_1=1

Calculated values: t_{m1}= 32.5 sec; 35.48 sec; 40.8 sec.

t_{m2}= 30.80 sec; 31.15 sec; 31.93 sec.

Measured values: t_{mas}= 30.47 sec; 30.36 sec; 31.55 sec.

t_{mr}= 40 sec, recommended time. It is observed again that $\boldsymbol{t_0} < \boldsymbol{t_{mr}}$**;**

For the same SICOMA mixer with capacity of 2.0 mc it is considered the particularly case of high compressive strength concrete preparation, for which it was determined the values:

- for C 40/50, R_c = 54.7 N/mm^2; for C 50/60, R_c = 64.3 N/mm^2 .

t_0=60 sec, $\boldsymbol{k_1}$**=1.5**, for special concrete, subjected to heat treatment at pouring

Calculated values:

t_{m1}= 118.83 sec; 121.95 sec; t_{m2}= 92.5 sec; 94.05 sec;

Measured values: t_{mas}= 120.12 sec; 121.26 sec;

$\boldsymbol{t_0} = \boldsymbol{t_{mr}}$ **=60 sec** (for dried concrete)

c) Mixers with two horizontal axis

for SIMEM mixer with useful capacity of 1.0 mc, obtained values: for C 16/20,

R_c = 21.63 N/mm^2 ; for C 20/25, R_c = 27.27 N/mm^2; pentru C 25/30, R_c = 31.25 mm^2;

t_0=45 sec, k_1=1,

t_{mr}=30 sec recommended by the SIMEM mixer manufacturer; $\boldsymbol{t_0} > \boldsymbol{t_{mr}}$

calculated values : t_{m1}= 52.1 sec**;** 56.7 sec; 59.5 sec.

t_{m2}= 46.4 sec; 47.4 sec; 47.7 sec.

Measured values: t_{mas}= 45.12 sec; 46.22 sec; 46.67 sec.

- for C 35/45**,** R_c = 48,7 N/mm^2

t_0=30 sec , k_1=1

Calculated values: t_{m1}= 44.7sec; t_{m2}= 31.6 sec;
Measured value: t_{mas} =30.45 sec

t_m recommended by the SICOMA mixer manufacturer 40 sec;
It is observed again in this case that $\boldsymbol{t_0 < t_{mr}}$
For SICOMA mixer of 1.5 mc: for C 25/30, R_c = 41.5 N/mm^2;
for C 30/37 , R_c = 46.8 N/mm^2
t_0=30 sec, k_1=1
t_{mr} recommended by the SICOMA mixer manufacturer; $\boldsymbol{t_0 < t_{mr}}$
Calculated values: t_{m1}= 41 sec; 42.8 sec. t_{m2}= 32 sec; 32.03 sec.
Measured values: t_{mas} =30.22 sec; 31.15 sec;
For another mixer SICOMA of 1.5 mc: for C 25/30, R_c = 45.8 N/mm^2
t_{mr} recommended by the SICOMA mixer manufacturer; $\boldsymbol{t_0 > t_{mr}}$;t_0=45 sec, k_1=1
Calculated values:t_{m1}= 62 sec; t_{m2}= 48.05 sec; Measured value: t_{mas} =46.14 sec
For SICOMA mixer of 2.0 mc: for C 12/15, R_c = 19.6 N/mm^2 ; for C 16/20, R_c = 27.3 N/mm^2; for C 18/22.5, R_c = 26.4 N/mm^2; for C 25/30, R_c= 38.2 N/mm^2.
t_0=30 sec, k_1=1
t_{mr} recommended by the SICOMA mixer manufacturer 40 sec. $\boldsymbol{t_0 < t_{mr}}$
Calculated values: t_{m1}= 32.7 sec; 34.6 sec; 35.6 sec; 39.4 sec.
t_{m2}= 30.8 sec; 31.1 sec; 31.1 sec; 31.9 sec.
Measured values: t_{mas} =31.34 sec; 31.18 sec; 30.92 sec; 32.14 sec.

Graphic representation of the values from the three case studies

Figure 6.6 shows the variation of the mixing time with the compressive strength at 28 days on cubes, for mixers with a vertical axis with capacities of 0.5 m^3, 1.0 m^3 and 2.0 m^3, when preparing concrete with resistance classes C 12/15 - C 35/45.

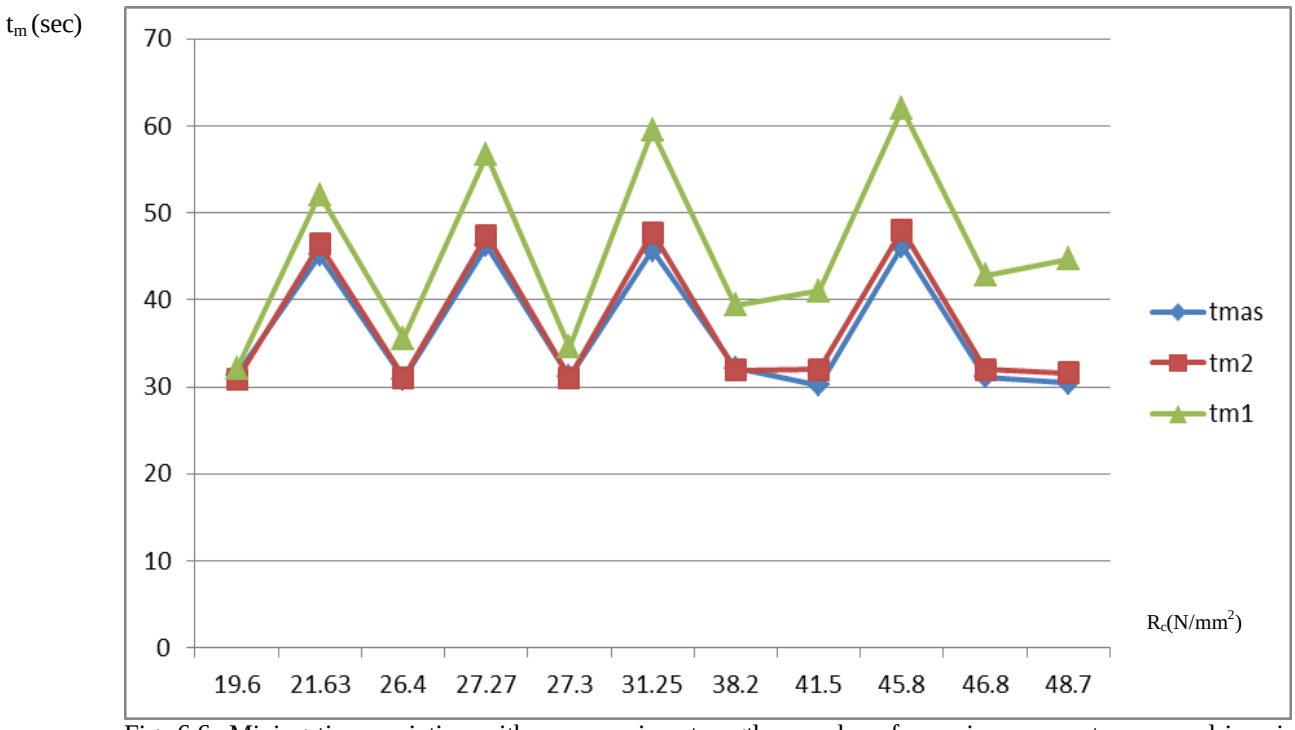


Fig. 6.6- Mixing time variation with compressive strength on cubes, for various concrete prepared in mixers with vertical axis, with different capacities

Figure 6.7 shows the variation of the mixing time with compressive strength, for mixers with two vertical axis, with capacities of 1.0 m^3, 1.5 m^3 and 2.0 m^3, when preparing concrete with resistance classes C 12 / 15 - C 50/60.

Figure 6.8 shows the variation of the mixing time with compressive strength on cubes, for mixers with two horizontal axis, with capacities of 1.0 m^3, 1.5 m^3 and 2.0 m^3, when preparing concrete with resistance classes C 12 / 15- C 35/45.

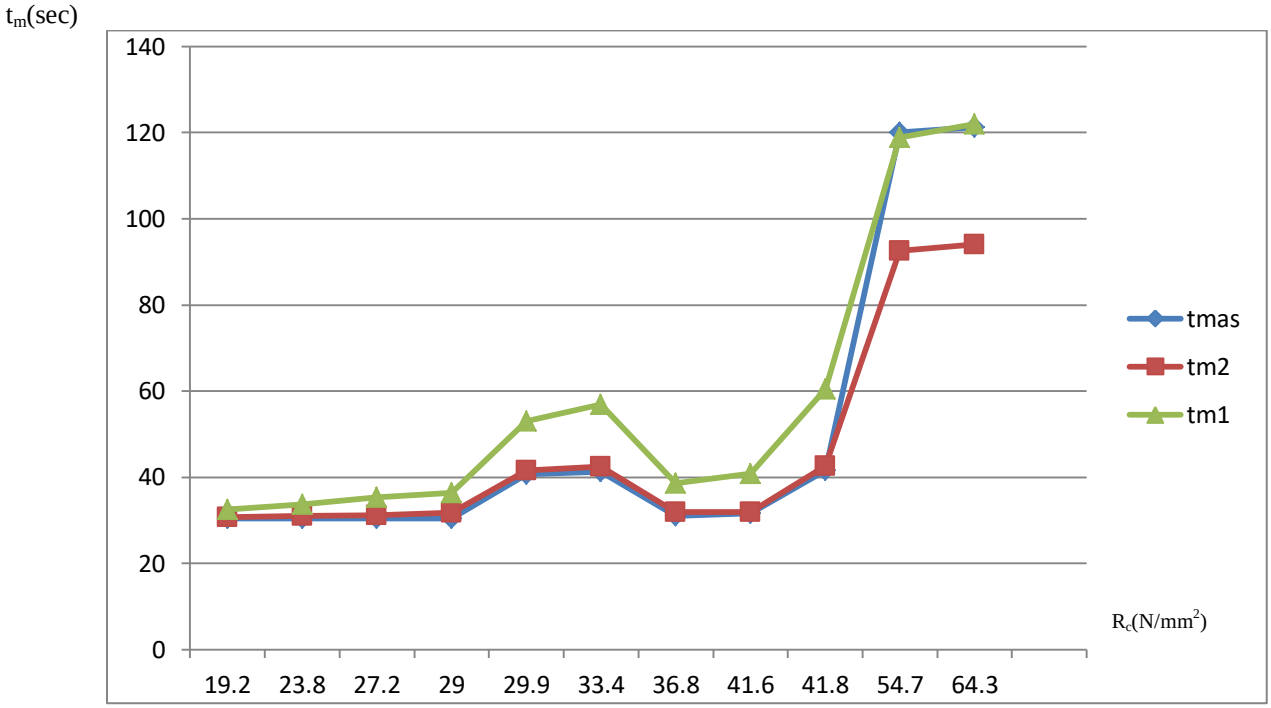


Fig. 6.7- Mixing time variation with compressive strength on cubes, for various concrete prepared in mixers with two vertical axis, with different capacities

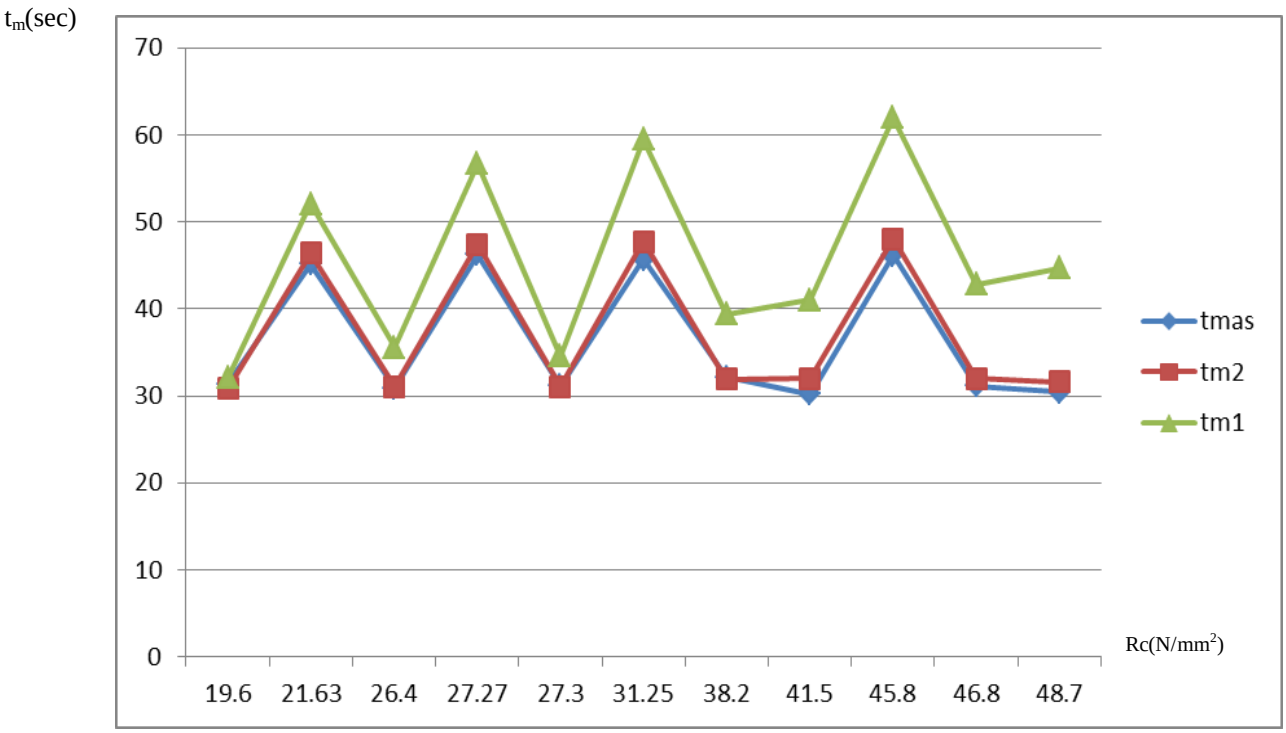


Fig. 6.8- Mixing time variation with compressive strength on cubes, for various concrete prepared in mixers with two horizontal axis, with different capacities

Conclusions. From the graphs presented in figures 6.6-6.8 the following conclusions can be summarized about the working mode of automated concrete stations:

- the values for t_{m2} and t_{mas} are very close, the actual mixing time being mathematically represented with great precision by the proposed relationship for t_{m2};
- the values resulting from the relation application for t_{m1} represent **PROPOSED values for a mixture better homogenization**;
- the values PROPOSED by the relation t_{m1} are confirmed by the approximation with the measured values from the case of the C 40/50 and C 50/60 class concrete preparation; in cases where the concrete prepation conditions involve additional efforts to homogenize ($k_1 > 1$) , the values resulting from that relationship application are COVERING.

Validation of the relationship between the mixing time and the compressive strength with the strength class variation, by determining the polynomial functions for the three mixing systems. Conclusions about concrete mixing

The case of the mixer with a vertical axis. It is considered the concrete preparation case of resistance class C 12 / 15- C 35/45 and consistency class S3, with the maximum aggregate granule ø 16 mm, using a mixer with a vertical axis and pallets, model LIEBHERR, useful capacity 1.0 m^3, rotor speed 26.4 rpm, engine power 37 kW. The values of the mixing time were measured with the stopwatch shown in figure 5.1. The compressive strength values for concrete C 12/15, C 16/20, C 20/25, C 25/30, C 30/37 and C 35/45 were determined in the laboratory which served the respective concrete plant.

Mixer factor calculation for the mixer with vertical axis of 1.0 mc capacity, **f_m= 0,12.**

Recipe factor calculation after dosing. It is applied the both relations f_{r2} și f_{r1} and it is determined the factors $k_2= f_r+ f_m$, in both variants, determining the values for t_{m2} și t_{m1}

The prepared concrete had the next characteristics:
- C 8/10, q= 2350 kg/mc, a/c= 0.72;
- C 12/15, q= 2356 kg/mc, a/c= 0.66;
- C 16/20, q= 2359 kg/mc, a/c= 0.61;
- C 20/25, q= 2369 kg/mc, a/c= 0.56;
- C 25/30, q= 2365 kg/mc, a/c= 0.51;
- C 30/37, q= 2370 kg/mc, a/c= 0.47;
- C 35/45, q= 2378 kg/mc, a/c= 0.41.

Calculated values for recipe factor:
- pentru C 12/15, f_{r2} = 0.0856; f_{r1} = 0.0856
- pentru C 16/20, f_{r2} = 0.0769; f_{r1} = 0.156
- pentru C 20/25, f_{r2} =0.0858; f_{r1} =0.228
- pentru C25/30, f_{r2} = 0.0877; f_{r1} = 0.296
- pentru C 30/37, f_{r2} = 0.0803; f_{r1} = 0.352
- pentru C 35/45, f_{r2} = 0.130; f_{r1} = 0.437.

Relation for t_m, $t_m=t_0k_1+t_0k_2\left(1-\frac{R_{c0}}{R_c}\right)$ was applied for the expected duration t_0 = 30 sec, the recommended mixing time being respected and for k_1 = 1.

The values obtained, presented in table 6.1 will be used to validate the relationship between the mixing time and the compressive strength, taking into account the values measured as experimental data t_{mas} and the values proposed by the relation t_{m1}.

Table 6.1- Values obtained for mixer with vertical axis

t_{mas} (sec)	30.54	30.78	31.16	31.52	31.68	31.9
t_{m2} (sec)	31.2	31.5	31.8	32.0	31.9	33.1
t_{m1}(sec)	32.8	35.4	37.2	39.2	41.2	43.5
R_c(N/mm^2)	18.4	28.9	32.9	38,7	48,7	52,7
Resistance class	C 12/15	C 16/20	C 20/25	C 25/30	C 30/37	C 35/45

The values calculated with the relation t_{m2} are very close to t_{mas} in most cases, so they demonstrate mathematically the concrete preparation way, with the attempt to keep the mixing time constant with the concrete class variation, for economic reasons.

Validation of the connection relations for the mixer with vertical axis

The validation of the connection relations is done by determining the polynomial functions in the case of the actual mixing times t_{mas} and the proposed mixing times t_{m1} considered optimal, in relation to the experimental values for the resistance determined in laboratory.

After the method validation, the aim is to determine the mixing time values for which **maximum values of the concrete compressive strength** are obtained.

Figures 6.9 and 6.10 show graphically the values obtained for the compressive strength compared to the measured values t_{mas} and the values t_{m1} of the mixing time and the related polynomial functions resulting Y = f (X).

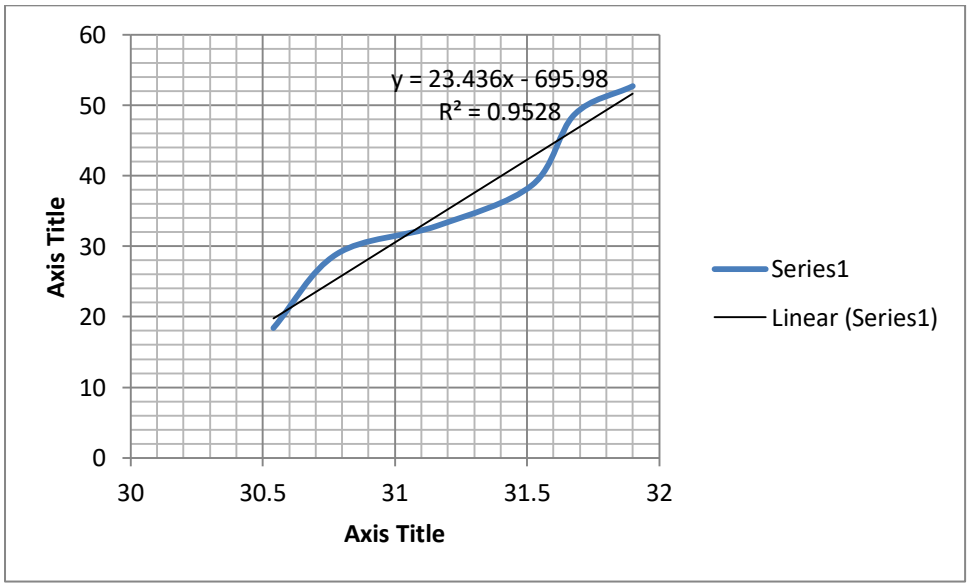


Figure 6.9- Polynomial function obtained for t_{mas} in relation with R_c at mixer with vertical axis

Calculation of mixing time for maximum compressive strength

The maximum compressive strength is defined as the minimum compressive strength plus 12 units [8] and the mixing time required to obtain the maximum compressive strength for each prepared concrete class is determined by applying both resulting polynomial functions.

Maximum compressive strength values - table 6.2 [8]:

R_{cmax}=27; 32; 37; 42; 49; 57 N /mm^2.

Tabel 6.2 –Recommended máximum strength of the concrete

Concrete resistance class	Minmum resistance at 28 days (Mba) on cubes	The range in which the average resistance should be found (Mpa)
C 8/10	10	16…22
C 12/15	15	21…27
C 16/20	20	26…32
C 18/22.5	22.5	28.5...34.5
C 20/25	25	31…37
C 25/30	30	36…42
C 28/35	35	41…47
C 30/37	37	43…49
C 32/40	40	46…52
C 35/45	45	51…57
C 40/50	50	56…62
C 45/55	55	61…67
C 50/60	60	66…72

a) The case of the polynomial function obtained by insertion of actually measured values. The polynomial function is:

R_c= 23.436 t_m – 695.98 (6.14)

Applying relation 6.14 we obtain values for t_m for which are obtained R_c maximum values :
- for class C12/15, t_m= 30.85 sec;
- for class C16/20, t_m=31.06 sec;
- for class C 20/25, t_m=31.27 sec;
- for class C 25/30, t_m=31.49 sec;
- for class C 30/37, t_m=31.78 sec;
- for class C 35/45, t_m=32.13 sec.

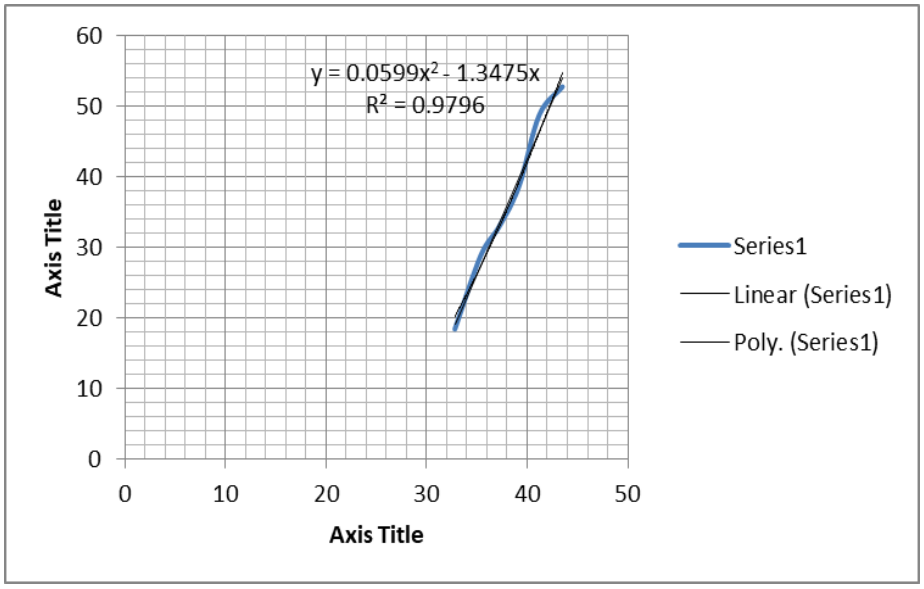


Figure 6.10- Polynomial function obtained for t_{m1} in relation with R_c at mixer with vertical axis

b) The case of the polynomial function obtained by insertion of proposed values for mixing time with relation t_{m1}. The polynomial function is:

R_c= 0.0599 t_m^2- 1.3475 t_m (6.15)

Applying relation 6.15 we obtain values for t_m for which are obtained R_c maximum values:
- for class C 12/15, t_m= 35.27 sec;
- for class C16/20, t_m=36.79 sec;
- for class C 20/25, t_m=38.52 sec;
- for class C 25/30, t_m=40.01 sec;
- for class C 30/37, t_m=41.98 sec;
- for class C 35/45, t_m=44.08 sec.

The case of mixer with two vertical axis. It is considered the concrete preparation case of resistance class C 12 / 15 - C 30/37 and consistency class S3, with the maximum aggregate granule ø 16 mm, using a mixer with two vertical axis and pallets, model SICOMA, useful capacity 2.0 m^3. The values of the mixing time were measured with the stopwatch from figure 5.1. and the compressive strength values for concrete C 12/15, C 16/20, C 18/22.5, C 20/25, C 25/30, and C 30/37 were determined in the laboratory which served the respective concrete plant.

Mixer factor calculation for the mixer with two vertical axis of 2.0 mc capacity, **f_m= 0,12.**

Recipe factor calculation after dosing. It is applied the both relations f_{r2} și f_{r1} and it is determined the factors k_2= f_r+ f_m, in both variants, determining the values for t_{m2} și t_{m1}.

The prepared concrete had the next characteristics:
- C 8/10, q= 2325 kg/mc, a/c= 0.70;

- C 12/15, q= 2328 kg/mc, a/c= 0.65;
- C 16/20, q= 2331 kg/mc, a/c= 0.61;
- C 18/22.5 q= 2327 kg/mc, a/c= 0.57;
- C 20/25, q= 2333 kg/mc, a/c= 0.53;
- C 25/30, q= 2341 kg/mc, a/c= 0.49;
- C 30/37, q= 2344 kg/mc, a/c= 0.45.

Calculated values for recipe factor:

- for C 12/15, f_{r2} = 0.072; f_{r1} = 0.072
- for C 16/20, f_{r2} = 0.063; f_{r1} =0.130;
- for C 18/22.5, f_{r2} =0.064; f_{r1} =0.186;
- for C 20/25, f_{r2} = 0.072; f_{r1} = 0.245;
- for C 25/30, f_{r2} = 0.078; f_{r1} = 0.304;
- for C 30/37, f_{r2} = 0.082; f_{r1} = 0.362.

Table 6.3- Values obtained for mixer with two vertical axis

t_{mas} (sec)	30.56	30.72	31.14	31.35	31.58	32.06
t_{m2} (sec)	31.05	31.1	31.2	31.4	31.7	31.9
t_{m1}(sec)	32.8	34.4	35.8	37.2	39.05	41
R_c(N/mm^2)	19.7	24.1	27.2	29.3	34.7	41.6
Resistance class	C 12/15	C 16/20	C 18/22.5	C 20/25	C 25/30	C 30/37

The relation 6.12 was applied for duration t_0 = 30 sec (the recommended mixing time being 40 sec for SICOMA mixer), and for k_1=1 . The values obtained are presented in table 6.3

Validation of the connection relations for the mixer with two vertical axis

The validation of the connection relations is done by determining the polynomial functions in the case of the actual mixing times t_{mas} and the proposed mixing times t_{m1} considered optimal, in relation to the experimental values for the resistance determined in laboratory.

After the method validation, the aim is to determine the mixing time values for which **maximum values of the concrete compressive strength** are obtained. The two polynomial functions Y= f(X) for the mixer with two vertical axis are shown in the figures 6.11 and 6.12.

Calculation of mixing time for maximum compressive strength

Values of **maximum compressive strength** for the six prepared concrete classes

- table 6.2 [8]:R_{cmax}=27; 32; 34,5; 37; 42; 49 N /mm^2.

a) The case of the polynomial function obtained by insertion of actually measured values:

R_c= 13.733 t_m – 399.49 (6.16)

Applying relation 6.16 we obtain values for t_m for which are obtained R_c maximum values:

- for class C12/15, t_m= 31.05 sec;
- for class C16/20, t_m=31.42 sec;
- for class C 18/22.5, t_m=31,60 sec;
- for class C 20/25, t_m=31.78 sec;
- for class C 25/30, t_m=32,14 sec;
- for class C 30/37, t_m=32.65 sec

b) The case of the polynomial function obtained by insertion of proposed values for mixing time with relation t_{m1}:

R_c= 0.0479 t_m^2- 0.9671 t_m (6.17)

Applying relation 6.17 we obtain values for t_m for which are obtained R_c maximum values:

- for class C12/15, t_m= 35.93 sec;
- for class C16/20, t_m=37.84 sec;
- for class C 18/22,5, t_m=38.76 sec;

- for class C 20/25, t_m=39.66 sec;
- for class C 25/30, t_m=41.38 sec;
- for class C 30/37, t_m=43.63 sec.

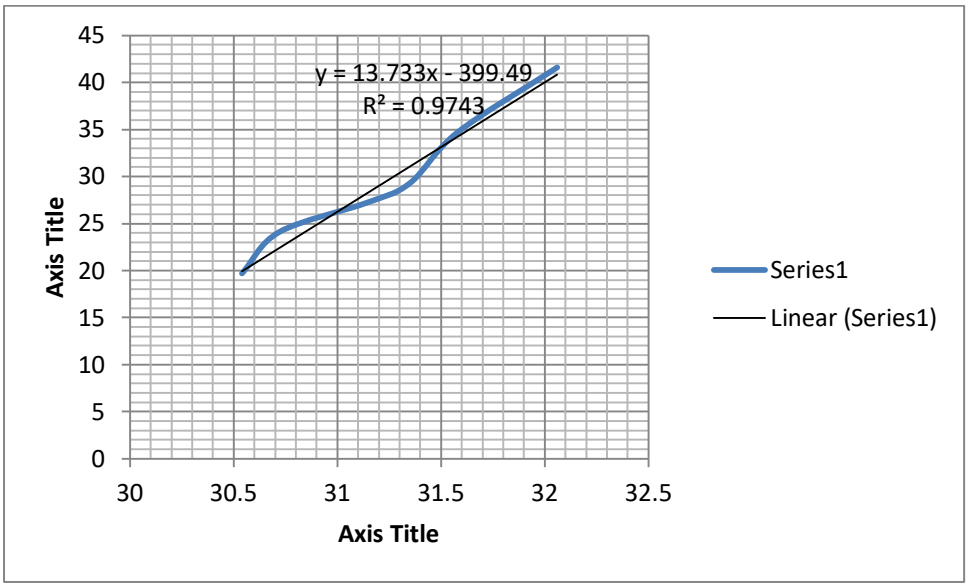


Figure 6.11- Polynomial function obtained for t_{mas} in relation with R_c at mixer with two vertical axis

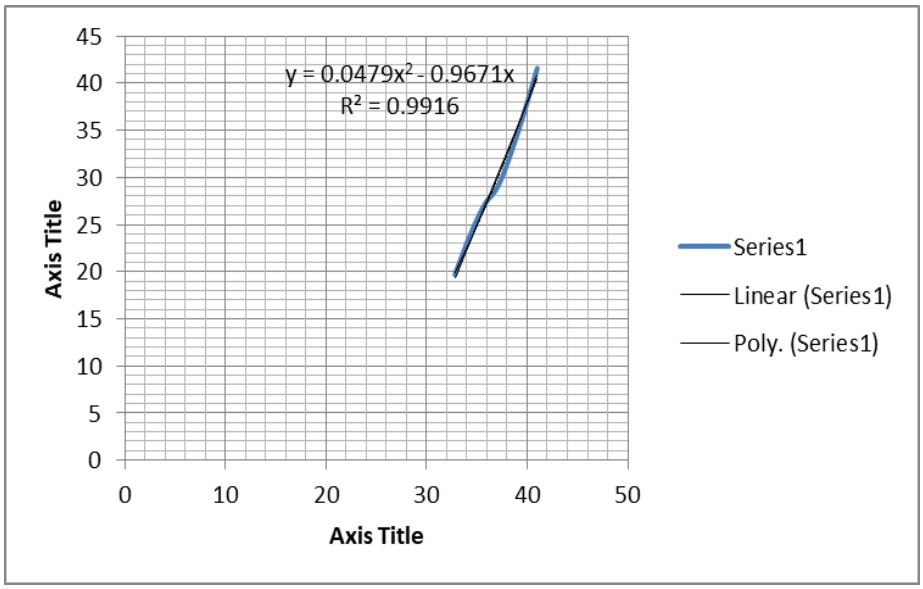


Figure 6.12- Polynomial function obtained for t_{m1} in relation with R_c at mixer with two vertical axis

The case of the mixer with two horizontal axis. It is considered the concrete preparation case of resistance class C 12/15- C 35/45 and consistency class S3, with the maximum aggregate granule ø 16 mm, using a mixer with two horizontal axis and pallets, model AMMANN, useful capacity 1.0 m^3. The values of the mixing time were measured with the stopwatch from figure 5.1. and the compressive strength values for concrete C 12/15, C 16/20, C 20/25, C 25/30, C 30/37 și C 35/45 were determined in the laboratory which served the respective concrete plant.

Mixer factor calculation for the mixer with two horizontal axis of 1.0 mc capacity, **f_m= 0,18.**

Recipe factor calculation after components dosing.

The prepared concrete had the next characteristics:

- C 8/10, q= 2330 kg/mc, a/c= 0.75;
- C 12/15, q= 2336 kg/mc, a/c= 0.69;

- C 16/20, q= 2329 kg/mc, a/c= 0.63;
- C 20/25, q= 2339 kg/mc, a/c= 0.57;
- C 25/30, q= 2341 kg/mc, a/c= 0.50;
- C 30/37, q= 2338 kg/mc, a/c= 0.45;
- C 35/45, q= 2342 kg/mc, a/c= 0.40.

Calculated values for recipe factor:
- for C 12/15, f_{r2} = 0.082; f_{r1} = 0.082;
- for C 16/20, f_{r2} = 0.084; f_{r1} = 0.159
- for C 20/25, f_{r2} =0.099; f_{r1} =0.243;
- for C25/30, f_{r2} = 0.123; f_{r1} = 0.336;
- for C 30/37, f_{r2} = 0.099; f_{r1} = 0.402;
- for C 35/45, f_{r2} = 0.112; f_{r1} = 0.469.

The relation 6.12 was applied for duration t_0 = 50 sec (the recommended mixing time being 40 sec for AMMANN mixer), and for k_1=1 . The values obtained are presented in table 6.4

Table 6.4- Values obtained for mixer with two horizontal axis

t_{mas} (sec)	51,26	52,34	52,46	53,81	54,32	55,18
t_{m2} (sec)	52,3	52,8	53,5	54,5	53,8	54,3
t_{m1}(sec)	57,5	61,4	65,1	69,1	72,4	76,2
R_c(N/mm^2)	23,5	30,6	34,8	38,8	43,7	52,6
Resistance class	C 12/15	C 16/20	C 20/25	C25/30	C 30/37	C 35/45

Validation of the connection relations for the mixer with two horizontal axis

The validation of the connection relations is done by determining the polynomial functions in the case of the actual mixing times t_{mas} and the proposed mixing times t_{m1} considered optimal, in relation to the experimental values for the resistance, determined in laboratory.

After the method validation, the aim is to determine the mixing time values for which **maximum values of the concrete compressive strength** are obtained. The two polynomial functions Y= f(X) for the mixer with two horizontal axis are shown in the figures 6.13 and 6.14.

Calculation of mixing time for maximum compressive strength

Values of **maximum compressive strength** for the six prepared concrete classes
- table 6.2 [8]:R_{cmax}=27; 32;; 37; 42; 49; 57 N /mm^2.

a) The case of the polynomial function obtained by insertion of actually measured values:
R_c= 6.8683 t_m – 328.26 (6.18)

Applying relation 6.18 we obtain values for t_m for which are obtained R_c maximum values:
- for class C12/15, t_m= 51.72 sec;
- for class C16/20, t_m=52.45 sec;
- for class C 20/25, t_m=53.18 sec;
- for class C 25/30, t_m=53.90 sec;
- for class C 30/37, t_m=54.92 sec;
- for class C 35/45, t_m=56.09 sec.

b) The case of the polynomial function obtained by insertion of proposed values for mixing time with relation t_{m1}:
R_c= 0.0135 t_m^2- 0.352 t_m (6.19)

Applying relation 6.19 we obtain values for t_m for which are obtained R_c maximum values:
- for class C12/15, t_m= 59.61 sec;
- for class C16/20, t_m=63.42 sec;

- for class C 20/25, t_m=66.97 sec;
- for class C 25/30, t_m=70.31 sec;
- for class C 30/37, t_m= 74.66 sec;

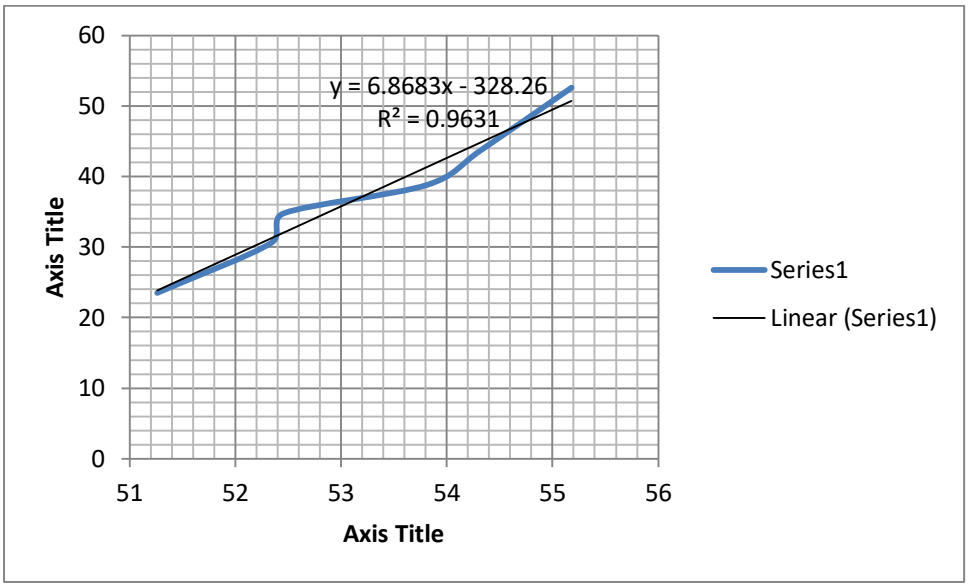


Figure 6.13- Polynomial function obtained for t_{mas} in relation with R_c at mixer with two horizontal axis

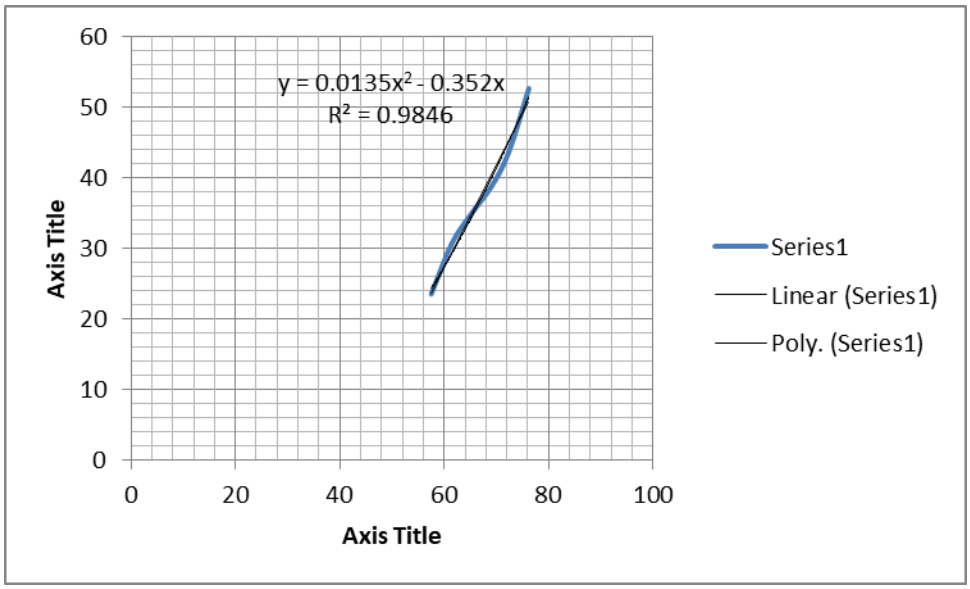


Figure 6.14- Polynomial function obtained for t_{m1} in relation with R_c at mixer with two horizontal axis

Conclusions on the values obtained for the three types of mixers:

- the regression factors obtained for all six variants of polynomial functions are good, with values between 0.95 and 0.99, being higher for the mixing system with two vertical axes (due to the "planetary" system) and lower for the kneading system with a vertical shaft;
- the regression factors obtained for the values calculated with the proposed relation t_{m1} are superior to those obtained at the introduction of the effective durations, which indicates the validity of the proposed method of establishing the variation of the mixing time with the strength class of the concrete;
- taking into account the mixing factor of each system, the volume of the concrete load and the mixing times measured and determined with the proposed relationships, it can be concluded that the homogenization of fluid and semi-dry concrete is easier to achieve in one

or two vertical axis mixers in relation to the two horizontal axis mixers, the latter being more efficient in the preparation of heavy concrete, road concrete and cement-stabilized ballast.

CHAPTER VII

PERSONAL CONTRIBUTIONS AND FUTURE RESEARCH DIRECTIONS

Personal contributions of the author of this doctoral thesis:
a) carrying out an evaluation of the current state of research in the field of parameters real-time monitoring of the of manually controlled, automated or modernized concrete stations;
b) analysis of performance levels for various concrete plants;
c) the study of the operational reliability of the automated concrete stations;
d) mathematical modeling of mixing for concrete mixers with vertical axis;
e) carrying out an experimental comparative study on a representative batch of concrete stations;
f) proposing correlation relations of the mixing duration with the concrete compression strength, validation of the proposed relations by determining the afferent polynomial functions and finding the values of the mixing duration corresponding to the maximum compressive strengths.

***Future research directions*:**
- the correlation of the mixing time with the compressive strength for each concrete class, by the mixing time variation for that resistance class and determining in different concrete stations the values of the mixing time for which the concrete reaches its maximum resistance;
- the analysis by technical inspections of the reliability in operation and the automation level of the equipments that enter in the the concrete stations endowment at national level, as well as the pursuance of the quality assurance degree of the prepared concretes in the modernized concrete stations;
- verification during the technical inspections of the implementation degree at national level of the monitoring in operation concept for concrete truck-mixers, by installing GPS programs;
- implementation by performing technical inspections of the performance level multicriteria analysis for asphalt mixed preparation installations, equipped with real-time monitoring systems of the main parameters.

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