RESEARCH ON QUALITY DIFFERENCES BETWEEN READY MIX CONCRETE PRODUCED USING A CONCRETE MIXER (WET) AND THE ONE PRODUCED USING DIRECT LOADING INTO A TRANSIT MIXER (DRY)

FINAL REPORT

Ordering party: ATECAP/UCOMESA/ANIMA Working Group
Order: 0671006 PRO
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Attn. of : Ing. Nicoziani

1 INTRODUCTION

The ATECAP/UCoMESA Working Group has entitled the Italian Concrete Institute to provide services and effect tests in order to fulfil a comparative research on characteristics of concretes, produced using a dry mixing process (hereafter called DRY) and a humid mixing prosess (hereafter called WET).

2 RESEARCH SUBJECT

The research is meant to identify possible quality differences between the concrete produced using a stationary concrete mixer (WET mixing process) and the one produced by direct loading the components into a transit mixer (DRY mixing process). The research is based on the evaluation of a range of proprieties of concrete, produced using both processes: homogeneity, workability, strength and permeability in comparable conditions (same raw materials, same processing, same equipment). Furthermore, test results are subjected to appropriate statistical tests, in order to show statistic relevance of result differences, obtained with the two methods.

3 REFERENCE STANDARDS

Criteria and regulations required by the following standards were applied to research methods and tests:

- · D.M. 25/09/2005 Technical standards for Construction.
- · UNI EN 206-1 Concrete - Part 1: Specification, proprieties, production and conformity.
- · UNI EN 11104 Concrete - Specification, proprieties, production and conformity – Complementary instructions for application of UNI EN 206-1.
- · ISO 18650 - 2 - Procedures for examination of mixing efficiency.
- · UNI EN 12350-1:2001 – Fresh concrete tests – Sampling.
- · UNI EN 12350-2:2001 - Fresh concrete tests – Slump test.
- · UNI EN 12350-6:2001 - Fresh concrete tests – Volume weight
- · UNI EN 12350-7:2002 - Fresh concrete tests – Air content – Pressure method.
- · UNI EN 12390-1:2002 – Consolidated concrete tests – Form, dimensions and requirements for samples and concrete formworks.
- · UNI EN 12390-2:2002 - Consolidated concrete tests – Processing and curing of samples for resistance tests.
- · UNI EN 12390-3:2003 - Consolidated concrete tests - Compressive strength of samples
- · UNI EN 12390-7:2002 - Consolidated concrete tests – Volume weight of consolidated concrete.

4. DEFINITIONS

- · Working unit: a group of companies, (minimum quantity equal to 3 is recommended) able to provide the operative support for concrete producing and sampling at a batching plant as well as at a building site.
- · Sampling: quantity of material, required for testing of fresh concrete and processing of n.02 cubic samples for consolidated concrete tests.
- · Range: a group of at least 15 samples
- · Humid processing: mixing by concrete mixer (“wet”)
- · Dry processing: mixing by direct loading into a transit mixer (“dry”)
- · Stage: a period of time needed to complete all operations included between loading and washing of a transit mixer.

5 OPERATIONAL PROCEDURES

Sampling and testing were carried out at the batching plants of each company selected by the "Ordering party".
All plants were required to have the characteristics described at 5.1.
Each plant had to use the same raw materials (cement, aggregates, additives and chemicals) and the same equipment (transit mixer) during the test.
In order to have a wide range of results, tests were carried out on 4 different types of concrete:

- Rck 50 consistence S5 (period of January)
- Rck 35 consistence S5 (period of January)
- Rck 30 consistence S4 (period of February)
- Rck 25 consistence S4 (period of April)

The operational sequence suggested for each plant and for each mixture was unchangeable and followed the procedure below:

a) loading of concrete produced using DRY mixing system and, after that, loading of concrete produced using WET mixing system (or vice versa) into a 10m3 volume transit mixer;

b) after the settling time (in case of DRY mixing system) or after mixing is finished (WET mixing system), concrete must be discharged in a neighbouring area in sub-volumes of 2 m3, in order to take samples for fresh concrete testing (as described in point 5.4).

To estimate the consistency of the proprieties along the time and concrete conditions after delivery, they simulate a transit period of 20 min.:

c) loading the same transit mixer keeping it turning at low speed for 20 min.
After that, materials are mixed at high speed (at least 100 revolutions of the drum) to repeat sampling, as described in point b)

d) after 40 min it wasn't possible to proceed with the whole sequence of point c) in any batching plant where tests were carried out.

The flowcharts below show the sequence of operations for each process.

6 PROCEDURE

6.1 GENERAL INSTRUCTIONS

Selected plants had to satisfy the following requirements:

- · loading point from concrete mixer is separated from the loading point of the direct feeding of the transit mixer
- · automatic weighing system of all components

- · raw materials had to be compliant with the effective standards. The quantity had to be sufficient to assure the consistency of the proprieties during all sampling period.
- · Transit mixers in a normal state of repair, equipped with pressure gauge with slump correlation and flowmeter
- · fresh concrete recycling system

It was prohibited to add any additives and/or any additional components once the loading was completed.

All test were effected between 09:00 and 17:00 in order to reduce the negative influence of atmosphere temperature.

Only PVC formworks made in conformity with effective standards were used for sampling.

6.2 MIX DESIGN

During the tests, mix designs available at the plants were used, selected by Ordering party among those able to provide concrete with the required characteristics, consistence variable between S3 and S5, produced using dry and wet mixing system. The characteristics of mix designs were different for each plant (besides different aggregates, cements of different strength classes and types, different additives, different gauging for cements of different strength classes, see attached concrete control schedules) but strictly identical for both systems inside every single plant.

6.3 SAMPLING

"Sampling" is to identify a quantity of material, sufficient to fulfil fresh concrete tests described below, and produce two specimens for consolidated concrete tests. The sampling was effected at least 8 times for each mix design and identified. Two sample ranges were produced the same day for each plant and for each mix design. One sample range was produced using WET mixing system and another one - using DRY mixing system.

The sampling was repeated on two subsequent loadings of 8 - 10 m3 of the same transit mixer: at T1 = 4 min before loading was finished and at T2 = 20 min before loading was finished. The total volume of 10 m3 transit mixer concrete was divided into 4 - 5 equal parts (so, sampling was made each 2 m3 of material).

Thus far, for each transit mixer there were produced two ranges of four – five samples (indicated with abbreviations P1D4… P5D4, P1D20… P5D20, P1W4… P5W4, P1W20… P5W20 on attached diagrams) and the whole sequence was repeated twice, the one for concrete, made using DRY system and the one for concrete made using WET system.

6.4 FRESH CONCRETE TESTING

For each sample the following tests were made:

- · Abrams slump test
- · volume weight

- · air content
- · water content verifying

6.5 CONSOLIDATED CONCRETE TESTS

Each time during sampling there were produced two cubic samples (total of (2x8) = 16 samples or (2x10) = 20 samples for each concrete mixture and for each processing method). In total there were produced n.32 samples for each mixture per day for first ad second plant and n.40 samples for the third plant.

All samples were marked with unalterable abbreviations and transferred to the IIC laboratories for the following tests:

- · Monoaxial compression strength in 7 days (4+4 or 5+5 samples)
- · Monoaxial compression strength in 28 days (4+4 or 5+5 samples)
- · Weight and volume measurements (all samples)
- · Permeability measurements (4+4 or 5+5 samples)

6.6 INTERPRETATION OF THE RESULTS

Results of all tests will be registered and elaborated using appropriate statistical methods (hypothesis test) in order to identify, for each batching plant, eventual statistically significant differences regarding values of consistency, strength and permeability of concretes produced using the two processings.
As far as results of statistical tests depends on characteristics of mixing equipment used at the plant (mixer type and transit mixer efficiency and type), all tests were effected considering results of concrete tests made on one (or more) mixture of one single plant.
Furthermore, statistical tests will be necessary for subsequent economical considerations.

6.7 SOURCES

The Italian Concrete Institute was present at each plant with its own equiped portable laboratory and n.2 members of technical support staff, in order to execute sampling and fresh concrete tests.
The portable laboratory was equipped with:

- · concrete sampling bucket
- · pan of a fixed measure
- · weight scale of 50 kg capacity
- · Abrams cone or impulse table
- · concrete thermometer and ambient thermometer
- · porosimeter
- · PVC formworks (n° 60 per plant)
- · needle vibrator
- · digital photocamera
- · accessories (test coupons, sampling certificates)

7. TEST REPORTS AND PUBLICATIONS

Each plant was provided with dossier, containing following datas:

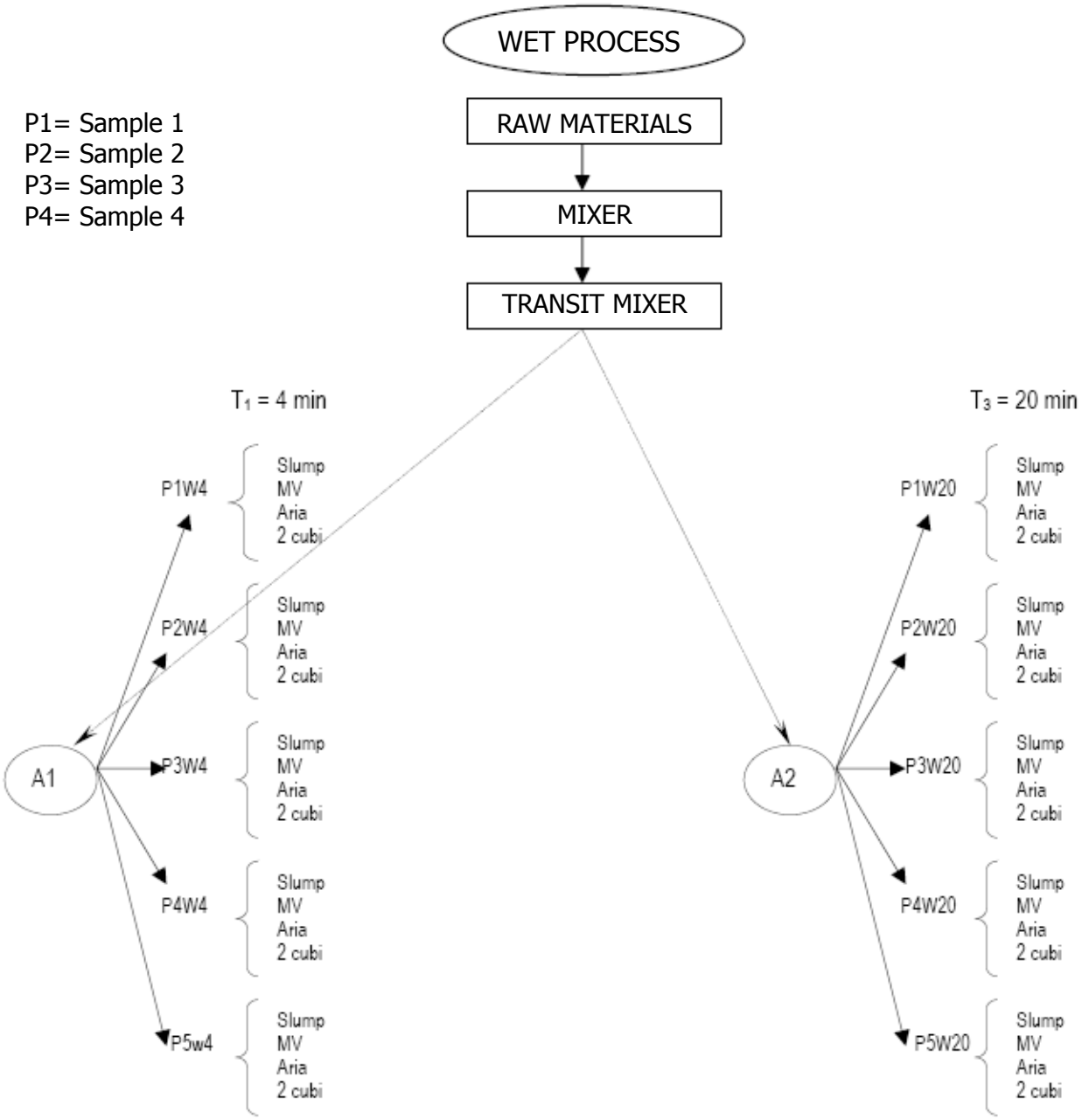
- · mixtures characteristics
- · relevant plant equipment characteristics (concrete mixer and transit mixer type)
- · sampling and testing reports
- · photografic documentation regarding tests effected at plant sites
- · final report containing statistical interpretation of results.

Following the specific instructions, provided by Ordering party about modality of report presentation (eventual omission of sampling sites, mixer types, ecc.) there will be prepared a technical article including (in simplifyed terms):

- · description of research project
- · sampling registration
- · obtained results
- · valid statistical issues

The style of the article will be technical/popular, to be published in specialized magazines or to be used in advertising/documentary materials. The article will be provided with significant range of pictures.
The Italian Concrete Institute is collaborating with the “La Fiaccola” publishing house, which has confirmed the publication and distributing of an article about the research.

P1= Sample 1
P2= Sample 2
P3= Sample 3
P4= Sample 4



P1= Sample 1
P2= Sample 2
P3= Sample 3
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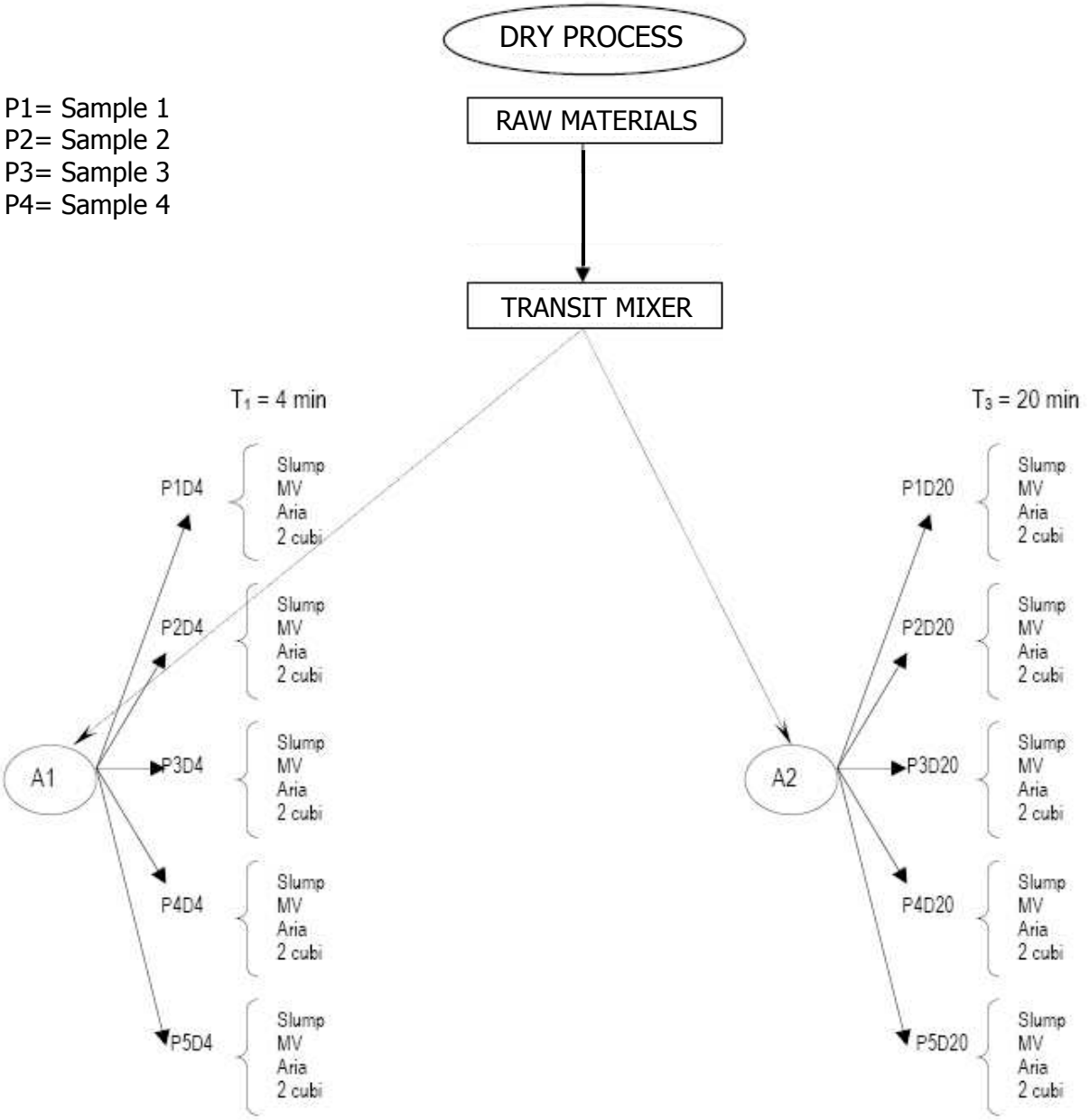


8 OBTAINED RESULTS

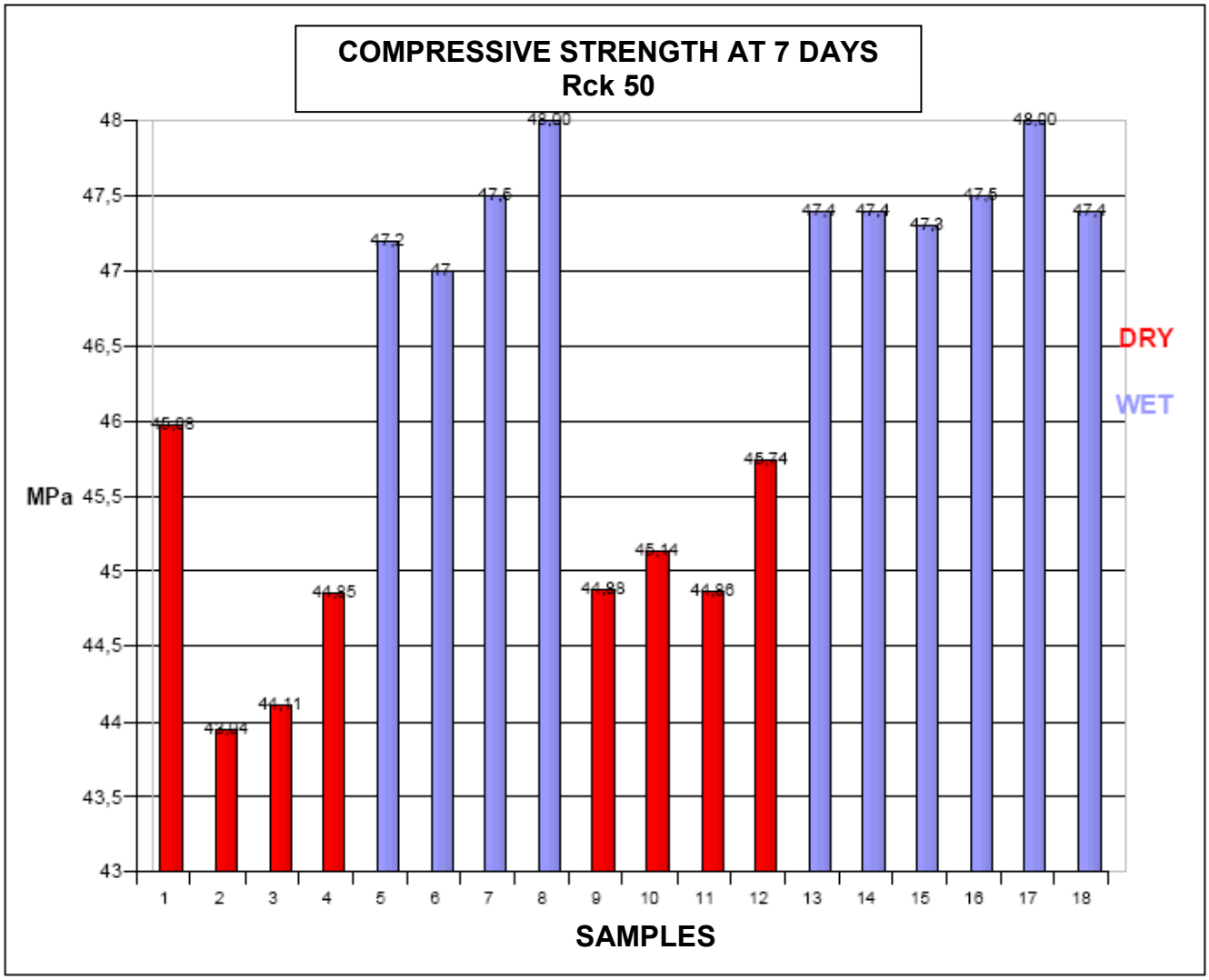
The results, obtained on four batching plants are the following:
D=DRY=TRANSIT MIXER, W=WET=MIXER

A

Rck 50 S5

SAMPLES	Weight 7 days (kg)	Compressive Strength at 7 days (MPa)	Weight 28 days (kg)	Compressive Strength at 28 days (MPa)	W/C	Abrams Cone Test (mm)	Permeability (mm)
P1D4	7,937	45,98	7,902	51,46	0,505	210	
P2D4	7,842	43,94	7,88	47,94	0,501	210	10
P3D4	7,896	44,11	7,9	49,02	0,490	200	6
P4D4	7,898	44,85	8,004	48,40	0,482	180	
media DRY "4 min"	**7,893**	**44,720**	**7,922**	**49,205**	**0,495**	**200**	**8**
P1W4	8,068	47,2	8,190	60,2	0,454	220	
P2W4	8,034	47	8,027	59	0,457	215	1
P3W4	8,120	47,5	8,095	59,5	0,456	215	
P4W4	8,205	48,00	8,299	61,00	0,451	200	0,5
media WET "4 min"	**8,107**	**47,425**	**8,153**	**59,925**	**0,454**	**213**	**0,8**
P1D20	7,906	44,88	7,910	52,42	0,487	190	
P2D20	7,92	45,14	7,89	51,43	0,493	175	9
P3D20	7,875	44,86	7,64	50,20	0,477	160	8
P4D20	7,867	45,74	7,892	49,73	0,484	140	
media DRY "20 min"	**7,892**	**45,155**	**7,833**	**50,945**	**0,485**	**166**	**9**
P1W20	8,103	47,4	8,078	59,7	0,455	210	
P2W20	8,085	47,3	8,065	59,6	0,455	210	1,5
P3W20	8,120	47,5	8,192	60,54	0,453	205	
P4W20	8,205	48,00	8,336	61,60	0,451	200	1,5
media WET "20 min"	**8,128**	**47,550**	**8,168**	**60,360**	**0,454**	**206**	**1,5**
media DRY	**7,893**	**44,938**	**7,877**	**50,075**	**0,490**	**183**	**8**
media WET	**8,118**	**47,488**	**8,160**	**60,143**	**0,454**	**209**	**1**
% PRO WET	**2,85%**	**5,67%**	**3,59%**	**20,10%**	**-7,31%**	**14,33%**	**-86,36%**

Legenda:
- *media* stands for Average
- *PRO WET* stands for Improvement of the Wet Process compared to the Dry Process


COMPRESSIVE STRENGTH AT 7 DAYS
Rck 50
MPa
48
47,5
47
46,5
46
45,5
45
44,5
44
43,5
43
45,74
44,85
44,11
47,2
47
47,6
48,00
44,88
45,14
44,86
47,4
47,4
47,2
47,5
48,00
47,4
DRY
WET
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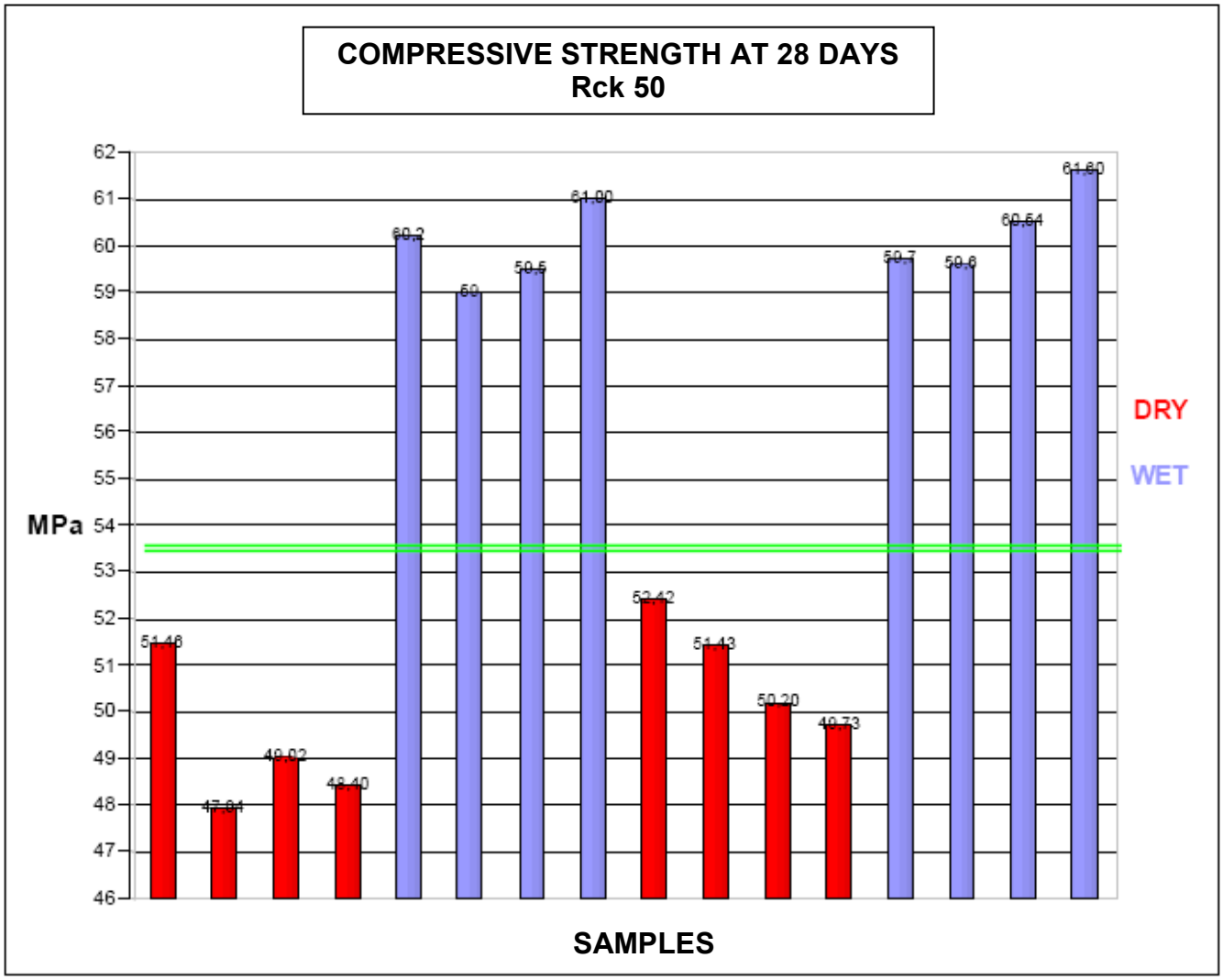
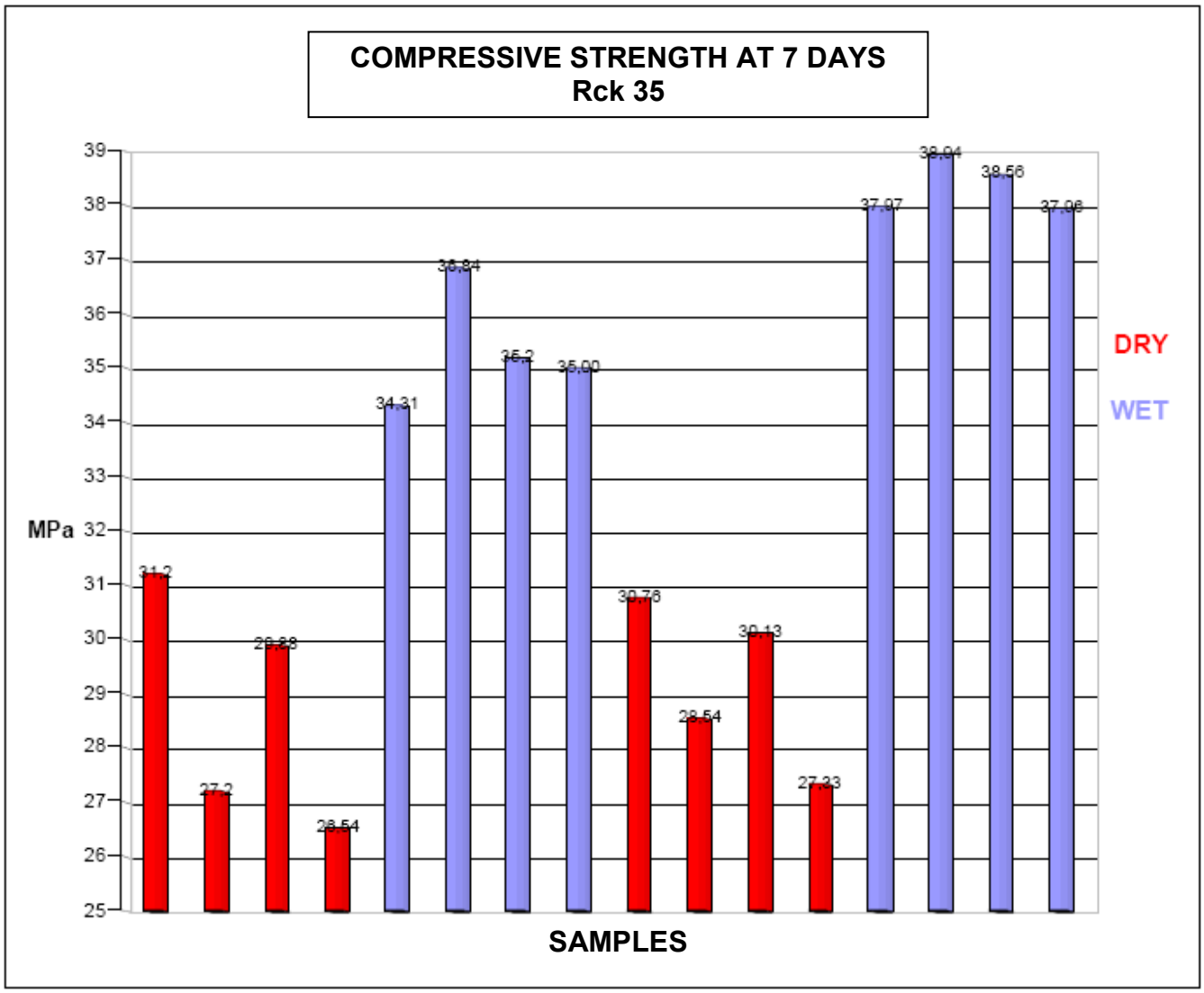
18
SAMPLES

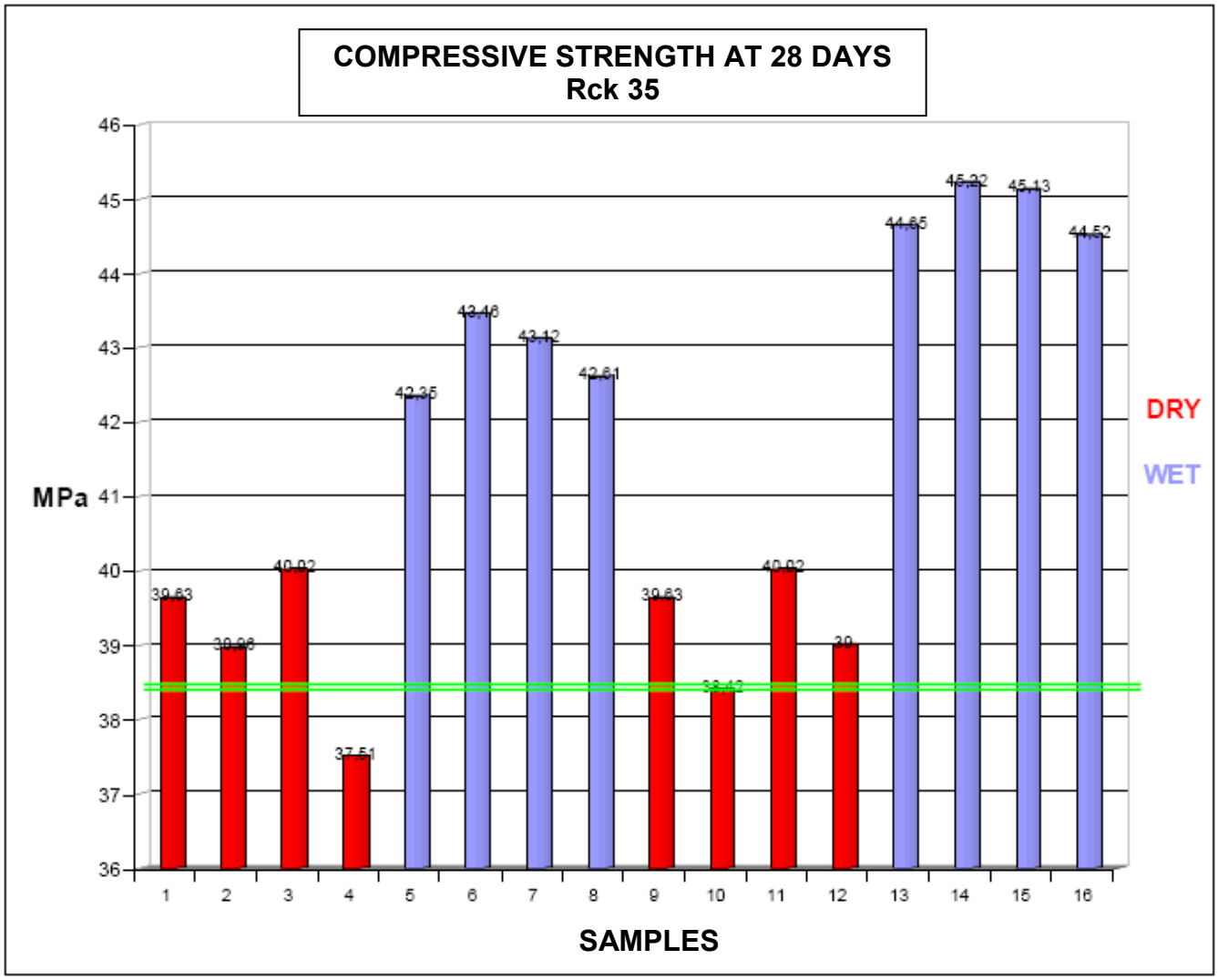


D=DRY=TRANSIT MIXER, W=WET=MIXER

	SAMPLES	Weight 7 days (kg)	Compressive Strength at 7 days (MPa)	Weight 28 days (kg)	Compressive Strength at 28 days (MPa)	W/C	Abrams Cone Test (mm)	Permeability (mm)
Rck 35 S5	P1D4	7,800	31,2	7,205	39,63	0,518	210	
	P2D4	7,100	27,2	7,084	38,96	0,524	200	15
	P3D4	7,470	29,88	7,276	40,02	0,509	190	
	P4D4	7,170	26,54	7,196	37,51	0,531	180	16
	media DRY "4 min"	**7,385**	**28,705**	**7,190**	**39,030**	**0,521**	**195**	**16**
	P1W4	7,757	34,31	7,810	42,35	0,488	220	
	P2W4	7,6915	36,84	7,811	43,46	0,480	215	4
	P3W4	7,723	35,2	7,81	43,12	0,480	215	4
	P4W4	7,758	35,00	7,813	42,61	0,483	210	
	media WET "4 min"	**7,732**	**35,338**	**7,811**	**42,885**	**0,483**	**215**	**4**
	P1D20	7,787	30,76	7,205	39,63	0,497	180	
	P2D20	7,225	28,54	6,985	38,42	0,510	160	14
	P3D20	7,097	30,13	7,276	40,02	0,495	160	
	P4D20	7,100	27,33	7,091	39	0,504	130	12
	media DRY "20 min"	**7,302**	**29,190**	**7,140**	**39,268**	**0,502**	**158**	**13**
	P1W20	7,872	37,97	7,835	44,65	0,481	210	
	P2W20	7,848	38,94	7,83	45,22	0,479	210	2
	P3W20	7,667	38,56	7,829	45,13	0,478	205	
	P4W20	7,835	37,96	7,828	44,52	0,480	200	3
	media WET "20 min"	**7,806**	**38,358**	**7,831**	**44,880**	**0,480**	**206**	**3**
	media DRY	**7,344**	**28,948**	**7,165**	**39,149**	**0,511**	**176**	**14**
	media WET	**7,769**	**36,848**	**7,821**	**43,883**	**0,481**	**211**	**3**
	% PRO WET	**5,79%**	**27,29%**	**9,15%**	**12,09%**	**-5,85%**	**19,50%**	**-77,19%**

Legenda:
- *media* stands for Average
- *PRO WET* stands for Improvement of the Wet Process compared to the Dry Process


COMPRESSIVE STRENGTH AT 7 DAYS
Rck 35
MPa
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
31,2
27,2
29,88
26,54
34,31
36,84
35,2
35,00
30,78
28,54
30,13
27,23
37,07
39,04
38,56
37,06
DRY
WET
SAMPLES

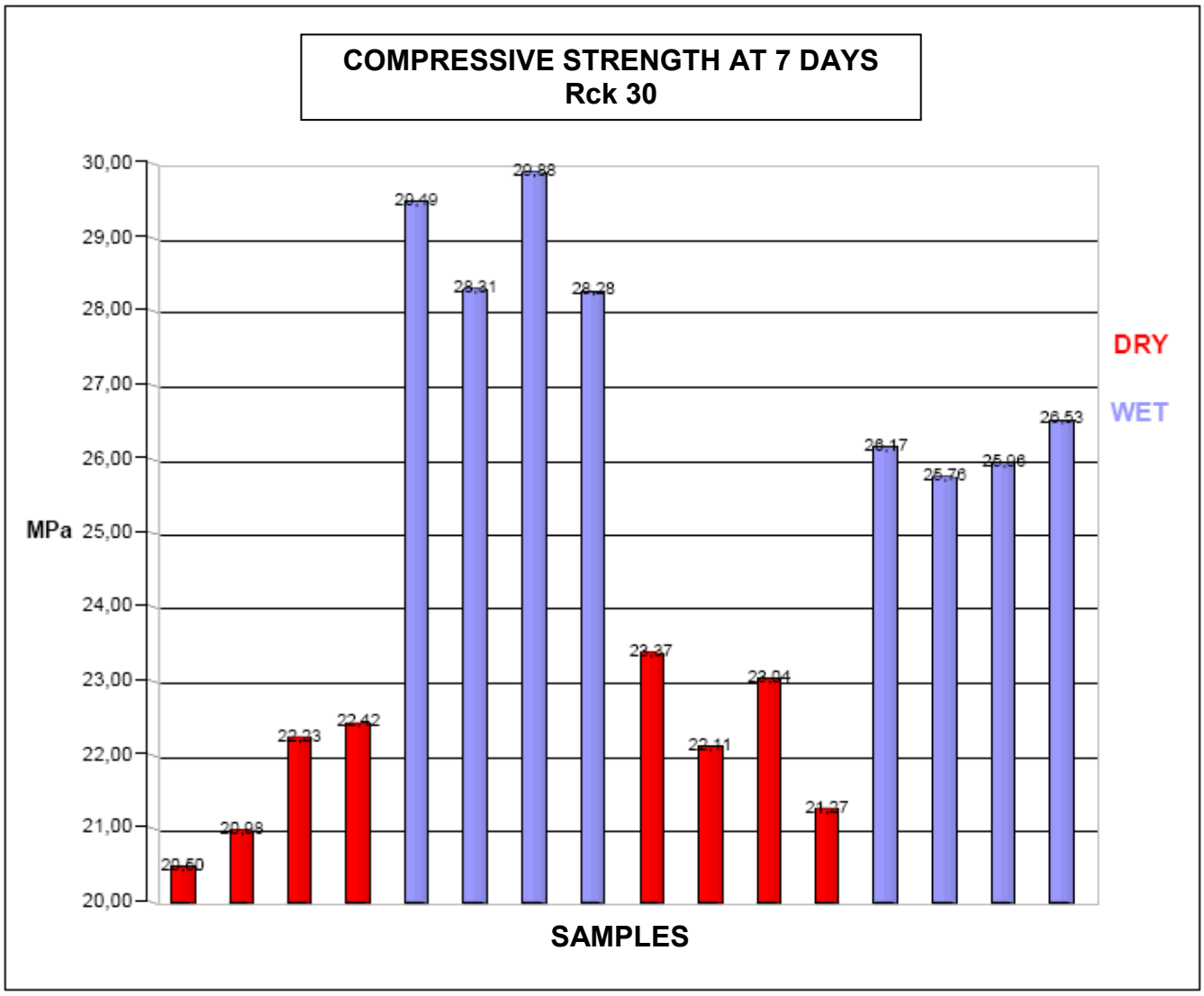


D=DRY=TRANSIT MIXER, W=WET=MIXER

C

Rck 30 S4

SAMPLES	Weight 7 days (kg)	Compressive Strength at 7 days (MPa)	Weight 28 days (kg)	Compressive Strength at 28 days (MPa)	W/C	Abrams Cone Test (mm)	Permeability (mm)
P1D4	7,558	20,50	7,376	31,79	0,632	235	
P2D4	7,529	20,98	7,406	32,58	0,610	210	40
P3D4	7,557	22,23	7,401	32,16	0,620	200	
P4D4	7,510	22,42	7,426	32,24	0,615	190	35
media DRY "4 min"	**7,539**	**21,533**	**7,402**	**32,193**	**0,619**	**209**	**38**
P1W4	7,634	29,49	7,508	38,01	0,553	190	
P2W4	7,610	28,31	7,543	37,66	0,558	180	10
P3W4	7,620	29,88	7,576	37,04	0,560	170	
P4W4	7,636	28,28	7,509	36,91	0,561	160	9
media WET "4 min"	**7,625**	**28,990**	**7,534**	**37,405**	**0,558**	**175**	**10**
P1D20	7,574	23,37	7,323	35,09	0,600	200	30
P2D20	7,597	22,11	7,404	31,79	0,637	180	
P3D20	7,503	23,04	7,464	31,38	0,640	190	45
P4D20	7,541	21,27	7,412	32,73	0,610	178	
media DRY "20 min"	**7,554**	**22,448**	**7,401**	**32,748**	**0,622**	**187**	**38**
P1W20	7,687	26,17	7,494	35,68	0,558	170	
P2W20	7,588	25,76	7,546	34,96	0,570	160	11
P3W20	7,583	25,96	7,46	35,43	0,561	155	
P4W20	7,547	26,53	7,518	35,25	0,565	150	12
media WET "20 min"	**7,601**	**26,105**	**7,505**	**35,330**	**0,564**	**159**	**12**
media DRY	**7,546**	**21,990**	**7,402**	**32,470**	**0,621**	**198**	**38**
media WET	**7,613**	**27,548**	**7,519**	**36,368**	**0,561**	**167**	**11**
% PRO WET	**0,89%**	**25,27%**	**1,59%**	**12,00%**	**-9,63%**	**-15,67%**	**-72,00%**


COMPRESSIVE STRENGTH AT 7 DAYS
Rck 30
30,00
29,00
28,00
27,00
26,00
25,00
24,00
23,00
22,00
21,00
20,00
MPa
20,60
20,98
22,23
22,42
29,49
28,31
29,98
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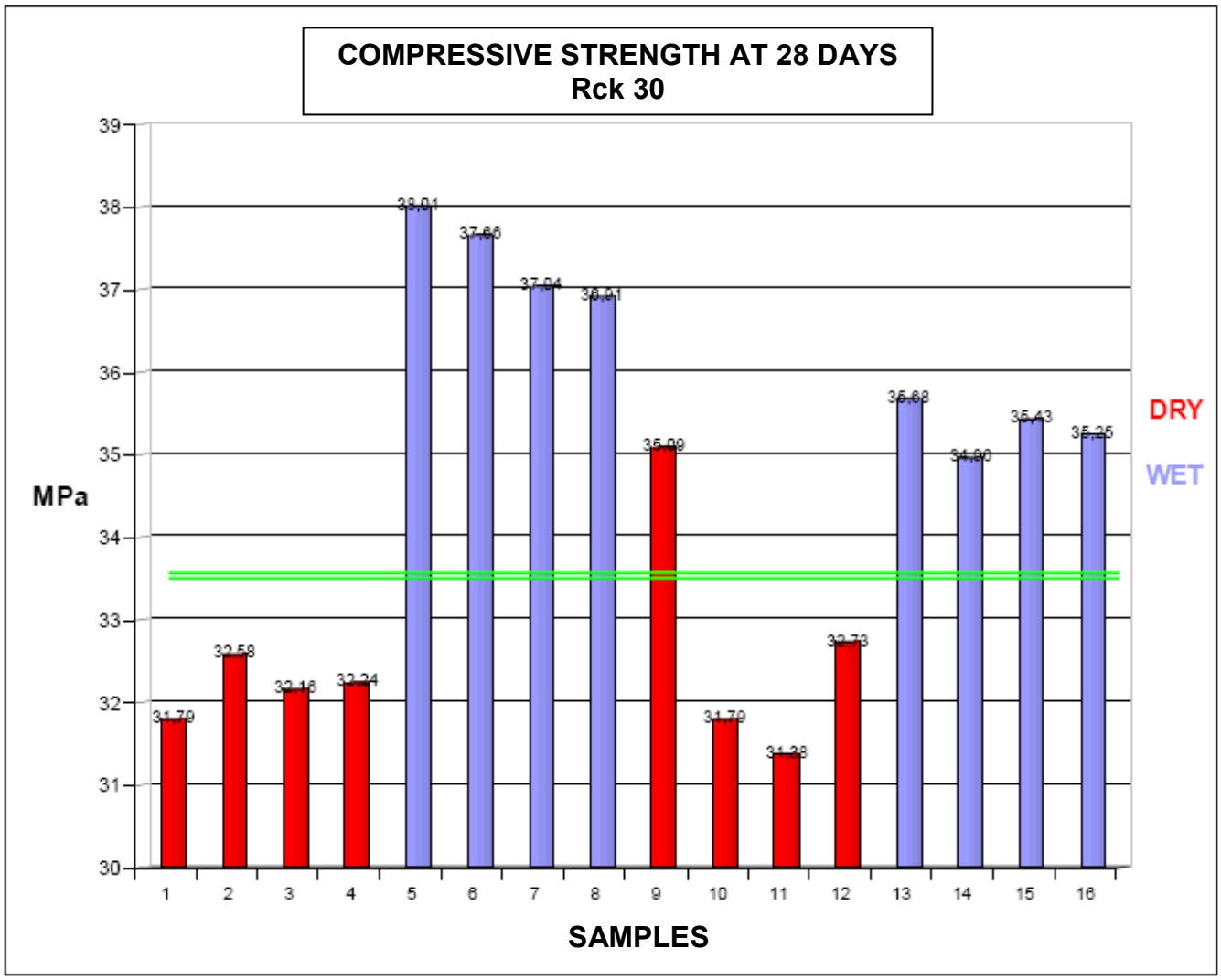
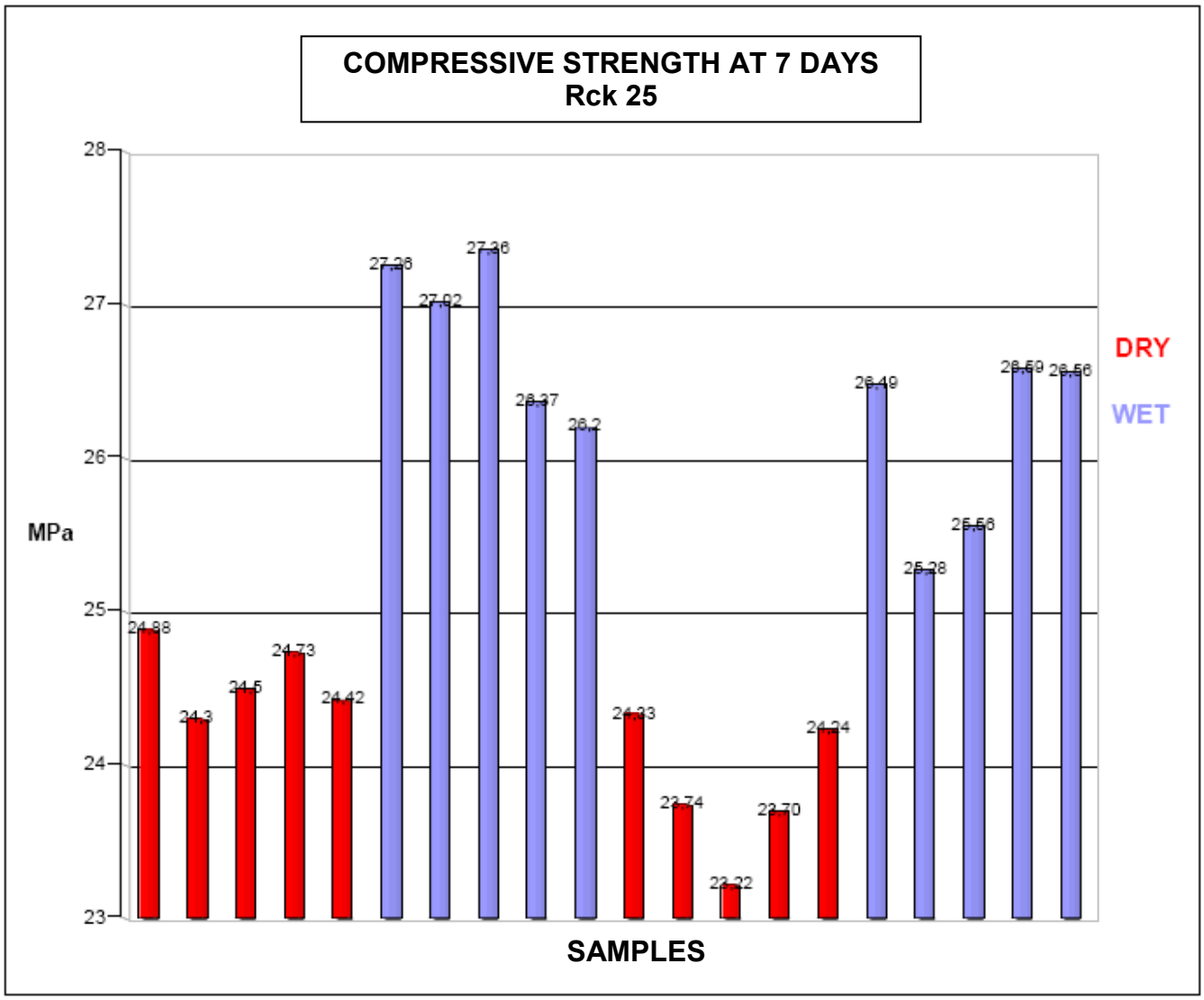
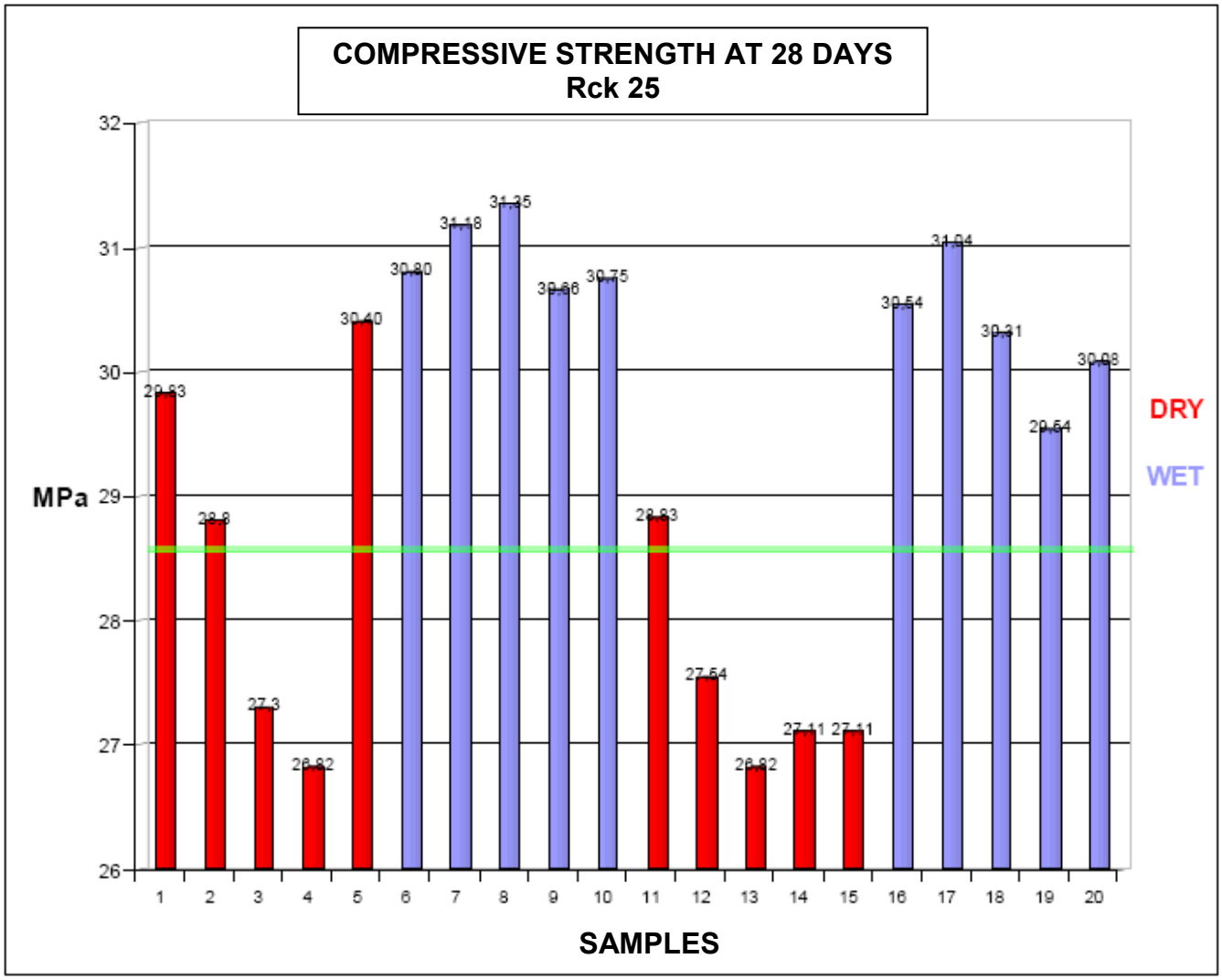
23,37
23,11
23,94
21,37
26,17
25,76
25,96
26,53
DRY
WET
SAMPLES

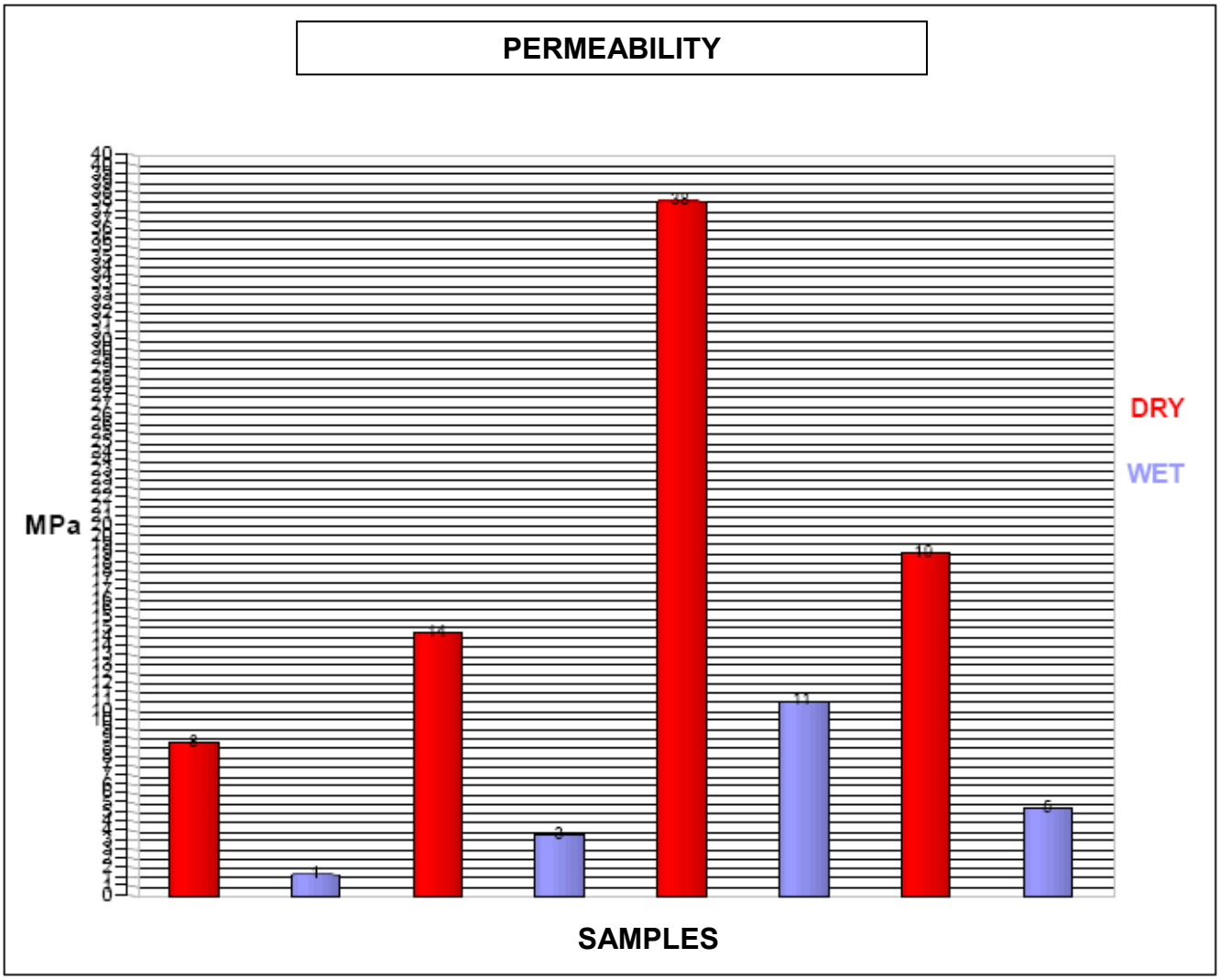


D=DRY=TRANSIT MIXER, W=WET=MIXER

D		SAMPLES	Weight 7 days (kg)	Compressive Strength at 7 days (MPa)	Weight 28 days (kg)	Compressive Strength at 28 days (MPa)	W/C	Abrams Cone Test (mm)	Permeability (mm)
	Rck 25 S4	P1D4	7,947	24,88	7,926	29,83	0,510	130	
		P2D4	8,029	24,3	7,849	28,8	0,517	135	15
		P3D4	7,950	24,5	7,963	27,3	0,526	140	
		P4D4	7,880	24,73	7,882	26,82	0,529	150	20
		P5D4	7,946	24,42	7,893	30,40	0,505	145	
		media DRY "4 min"	**7,950**	**24,566**	**7,903**	**28,630**	**0,517**	**140**	**18**
		P1W4	7,992	27,26	7,902	30,80	0,485	160	
		P2W4	7,999	27,02	7,987	31,18	0,480	170	5
		P3W4	7,988	27,36	7,904	31,35	0,478	175	
		P4W4	7,961	26,37	7,906	30,66	0,485	200	5
		P5W4	7,950	26,2	7,847	30,75	0,485	200	
		media WET "4 min"	**7,978**	**26,842**	**7,909**	**30,948**	**0,483**	**181**	**5**
		P1D20	7,913	24,33	7,837	28,83	0,530	100	
		P2D20	7,955	23,74	7,883	27,54	0,537	105	21
		P3D20	7,857	23,22	7,833	26,82	0,550	110	
		P4D20	7,846	23,70	7,767	27,11	0,540	115	18
			7,894	24,24	7,788	27,11	0,545	115	
		media DRY "20 min"	**7,893**	**23,846**	**7,822**	**27,482**	**0,540**	**109**	**20**
		P1W20	7,959	26,49	7,858	30,54	0,490	180	
		P2W20	7,878	25,28	7,815	31,04	0,481	190	4
		P3W20	7,868	25,56	7,879	30,31	0,489	185	
		P4W20	7,917	26,59	7,839	29,54	0,495	195	5
			7,928	26,56	7,838	30,08	0,492	200	
		media WET "20 min"	**7,910**	**26,096**	**7,846**	**30,302**	**0,489**	**190**	**5**
		media DRY	**7,922**	**24,206**	**7,862**	**28,056**	**0,529**	**125**	**19**
		media WET	**7,944**	**26,469**	**7,878**	**30,625**	**0,486**	**186**	**5**
		% PRO WET	**0,28%**	**9,35%**	**0,20%**	**9,16%**	**-8,11%**	**49,00%**	**-74,32%**


COMPRESSIVE STRENGTH AT 7 DAYS
Rck 25
MPa
28
27
26
25
24
23
24,88
24,3
24,5
24,73
24,42
27,26
27,02
27,36
26,37
26,2
24,23
23,74
23,22
23,70
24,24
26,49
25,28
25,68
26,59
26,56
DRY
WET
SAMPLES


COMPRESSIVE STRENGTH AT 28 DAYS
Rck 25
MPa
32
31
30
29
28
27
26
29.83
28.8
27.3
26.82
30.40
30.80
31.18
31.35
30.66
30.75
28.83
27.64
26.82
27.11
27.11
30.54
31.04
30.31
29.64
30.88
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
SAMPLES
DRY
WET



D=DRY=TRANSIT MIXER, W=WET=MIXER

	DESCRIZIONE	PESO 7 gg (kg)	RESISTENZA A COMPRESSIONE 7gg (Mpa)	PESO 28 gg (kg)	RESISTENZA A COMPRESSIONE 28gg (Mpa)	R a/c	CONSISTENZA abbassamento al cono (mm)	PERMEABILITA'
A	% PRO WET	2,85%	5,67%	3,59%	20,10%	-7,31%	14,33%	-86,36%
B	% PRO WET	5,79%	27,29%	9,15%	12,09%	-5,85%	19,50%	-77,19%
C	% PRO WET	0,89%	25,27%	1,59%	12,00%	-9,63%	-15,67%	-72,00%
D	% PRO WET	0,28%	9,35%	0,20%	9,16%	-8,11%	49,00%	-74,32%
	MEDIA	2,45%	16,90%	3,63%	13,34%	-7,72%	16,79%	-77,47%

The “blu” data are negative because the consistence class of concrete made in transit mixer exceeded the requested standard

9 CONCLUSIONS

The research on several plants, provided with concrete mixer, using both, WET and DRY processings, effected by our Institute has confirmed that the quality of concrete produced using a concrete mixer is undoubtedly higher, as shown by all values of our research.
Although, for several reasons, basically different mix designs we tested (Rck 50, Rck 35, Rck 30 e Rck 25), it was made globally evident that the concrete produced with stationary mixers have the following characteristics:

- total conformity to compression strength standards as for Rck required by mix design (100% samples after 28 days have largely reflected the specific strength required Rm ≥ Rck + 3,5; only average of 32% for dry system);
- the mixing effect of concrete mixers facilitate the complete cement hydration as confirmed by mix designs which, have higher strength class with the same quantity of cement used;
- using the same w/c proportion, WET concretes have higher workability and hydration;
- concrete homogeneousness (consistence, MV and, above all:
- lower permeability, as for UNI EN 12390-8: this data, apart from being proportional to lower R w/c for concretes produced with mixer, is also proportional to lower macroporosity (due to incomplete mixture compacting);
- total design mix repeatability.

However, the analysis of values shows that different mix design is not the only reason of deviations obtained during examination of different plants.

In fact, for some plants it may be really insignificant. And in these very cases it's necessary to keep investigating not only on mixing effects, but go further to know more about the quality level of used materials, stages of loading of single components and, above all, specialized personnel training.

In fact, the personnel should not be limited to knowing only mechanical or electronic parts, but should try to discover more about various mix designs to work with (for example: punctuality during cement loading, especially if it's hot, may form quite big bunches inside the mixture; moreover, reduced mixing times may deprive mixture of binding proprieties contained in bunches. As a consequence, strengths deviations will be reduced).

For The Italian Concrete Institute