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Effect of Dune Sand on the Properties of Flowing Sand-Concrete (FSC)

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Abstract: Sand-concrete is being researched for potential usage in construction in Saharan regions of Algeria, because of shortage in coarse aggregate resources. This research work deals with the effect of dune sand, available in huge quantities in these regions, on the properties of flowing sand-concrete (FSC) prepared with different proportions of dune and river sands. Mini-cone slump test, v-funnel flow-time test and viscosity measurements were used to characterize the behaviour of FSC in fresh state. The 28-day compressive strength was also determined. Test results show that an optimal content of dune sand, which makes satisfied fresh and hardened properties of FSC, is obtained. Moreover, the obtained flow index (constant b) calculated by the help of power-law viscosity model is successfully correlated to the experimental results of v-funnel flow time.

Keywords: flowing sand concrete, dune sand, fresh properties, viscosity, compressive strength.

1. Introduction

Due to the scarcity of aggregates in the south of Algeria and the high cost of their transportation from other regions, there has been a growing interest in the use of sand-concrete. Several research works have investigated the use of sand as a substitute for coarse aggregate to make sand-concrete, which has mechanical strength comparable to conventional concretes.[1-4] Usually, sand-concrete consists of a mixture of sands, cement, one or more admixtures, additions and water. It is to be distinguished from a conventional concrete by its high proportion of sand. It is also distinguished from mortar by its cement content (low dosage of cement) and especially by its destination, (sand-concrete is primarily intended for more traditional uses). This advantage becomes extremely interesting when sand-concrete can reach certain fluidity in order to improve some of their performances. In France, Sablocrete project has allowed establishing a standard and proposing a mix design method for sand-concrete. This project has also reported many applications of flowing sand-concrete (FSC) in concrete repairs, soil grouting and deep foundations for building.[1]

At present, local sands, which are only slightly or not at all extracted, constitute sizable deposits, and their application as construction materials would respond to the ecological and economic considerations raised by current trends.[2] Dune sand (DS), in particular, is available in huge quantities in the Sahara and cover more than 60 % of the area of Algeria.

In concrete design, the dosage and fineness of aggregates have an important influence on quality of fresh and hardened properties. Brouwers and Radix[5] have found that the fine sand is a useful component in optimizing the particle size distribution and thereby increasing flowability, stability and mechanical properties of the concrete mixes. Bédérina et al[2], show in a study on the reuse of local sands (dune and river sands) in sand -concrete, the importance of limestone filler content on the correction of particle size distribution and improvement of rheological and mechanical properties of studied sand-concretes.

Due to the finesses of aggregates in sand-concrete, it requires a high water demand and a large amount of cement than other types of concretes in order to achieve high fluidity. The increase in water content leads to detrimental effects including bleeding and segregation as well as weak interfaces between granular materials.[6,7] Moreover, high cement content may cause severe creep and drying shrinkage,[8] and may lead to classify sand-concrete as a mortar. For these reasons, sand-concrete mixes always contain a superplasticizer and a large quantity of additions. The superplasticizer is necessary for producing a flowable mix, while the addition of fine materials are required to maintain sufficient viscosity, hence reducing bleeding, segregation and settlement. However, excessive addition of fine particles can results in a considerable increase in the specific surface area of the powder, which results in an increase of water demand to achieve a given consistency.

In this work, a study on the effect of DS content on fresh properties and compressive strength of FSC is presented. For this, four mixes were prepared in which the sand was composed of a binary

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Table 1 Chemical composition and physical properties of cement and LP.

Compounds (%)	Cement	LP
CaO	63.55	53.1
SiO_2	23.24	0.54
Al_2O_3	4.72	0.29
Fe_2O_3	3.84	0.21
MgO	0.65	0.84
K_2O	0.4	0.05
SO_3	0.28	0.03
Na_2O	0.1	/
Cl	/	0.1
Free CaO	0.52	/
Insoluble residue	0.5	0.4
Loss of ignition	2.15	44.4
Specific density	3.1	2.7
Blaine Surface (cm^2/g)	3950	3200

Table 2 Sieve analysis and physical properties of used sands (DS and RS).

Sieve size (mm)	Cumulative passing (%)	
	DS	RS
5	100	99.5
4	100	97.09
2.5	100	83.56
1.25	99.92	63.27
0.63	98.09	34.85
0.315	82.86	13.65
0.16	19.36	2.44
0.08	1.63	0.84
Specific density	2.7	2.56
Fineness modulus	1	3.03
Sand equivalent	91	87.7
Absorption (%)	2.18	0.59
Moisture content (%)	1	0.33

blend of DS and river sand (RS) with different proportions of DS (0, 10, 20 and 30 %).

2. Experimental program

2.1 Materials

An ordinary Portland cement (CEM I 42.5) and a limestone type powder (LP) were used. The chemical and physical properties of cement and LP are given in Table 1. The sand used was a mixture of natural DS and RS. Selected sands are subjected to grain size distribution analysis as per XP P 18-540 standard.[9] The set of sieves are taken from 5 mm to 0.08 mm with aggregate and sieve shaker subjected to vibration for 15 minutes. The particle size gradation obtained thorough sieve analysis method and physical properties of DS and RS are grouped in Table 2. The obtained results show that DS is characterized by its fineness and cleanness. Moreover, X-Rays Diffraction (XRD) analysis and Scanning Electron Microscope (SEM) view of DS grains are given in Figs. 1 and 2 respectively. The XRD analysis of DS demonstrates their essentially siliceous nature and SEM investigation reveals the rounded shape of their fine grains. A polycarboxylate-type third generation high range water reducing superplasticizer (SP) conforming to the NF EN 934-2 standard[10] was used. The solid content, pH and specific gravity are 30 %, 6 and 1.07 respectively.

2.2 Mixtures proportions

The mix proportion method is based on optimizing the maximum packing mass volume of dry mixture[11]: The cement content is fixed, the LP content is selected, and the cement-LP mixture is completed by adding sand until obtaining a volume determined after dry mixing and 15 s of vibration on a vibrating table. Basing on the results of Bédérina et al.,[2] the LP/sand (LP/S) ratio was kept constant to 0.1. Four mixes were prepared having constant cement content of 350 kg/m^3, constant LP content of 146 kg/m^3, constant water/binder ratio (W/B) of 0.44 and a constant SP dosage of 1.5 %. A total sand content of 1456 kg/m^3 was used, in which RS was replaced by different proportions of DS (0, 10, 20 and 30% by weight of total sand). The different proportions of DS and RS are summarized in Table 3.

2.3 Testing procedures

As mentioned above, the sand used to prepare FSC mixes was

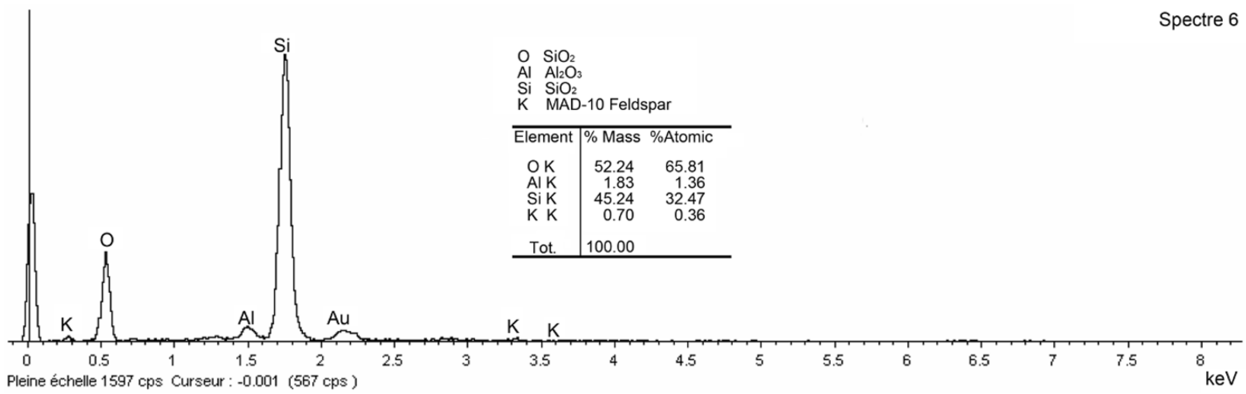

Fig. 1 X-Ray Diffraction pattern of DS.

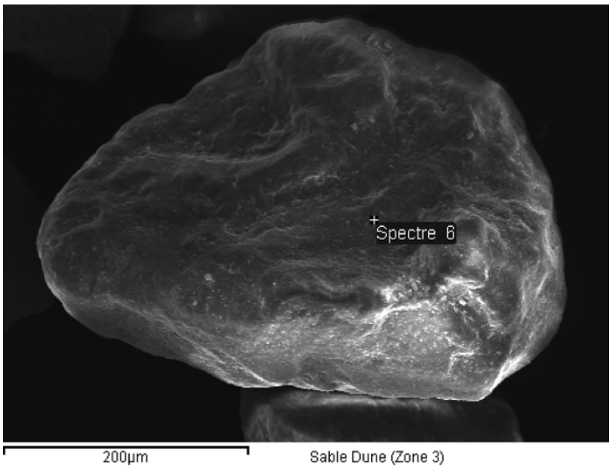

Fig. 2 View of fine DS grain (SEM analysis).

Table 3 Proportions of DS and RS in prepared mixes.

Mix N°	DS		RS
	%	(kg/m^3)	(kg/m^3)
1	0	0	1456
2	10	146	1310
3	20	291	1165
4	30	437	1019

composed from DS and RS with different concentrations of DS (0, 10, 20 and 30%). For that, the compactness of different sands used was measured at first, using their apparent and absolute densities as shown in the following relation.

$$C = \rho_{apparent}/\rho_{absolute} \quad (1)$$

Thereafter, all FSC mixes were prepared in identical mixing process to ensure similarity and uniformity. The mixing sequence consisted of homogenizing the binder and sands during one minute using standard mixer described by NF EN 196-1 standard.[12] Then, half of the mixing water was added and mixed for another one minute. Next, the remaining water and SP were added and the mixing was continued for three minutes.

The fresh properties of FSC were investigated by using mini-slump, v-funnel and viscosity tests. Mini-cone slump and v-funnel tests (Figs. 3 and 4) were used in conformity with EFNARC.[13]

The viscosity was measured using a programmable DV-II+ rotational viscometer equipped with the RV4 mobile geometry (Fig. 5). In this type of viscometer, slip was most pronounced at low strain rates and led to unusual low viscosity readings. As the deformation rate increased, the influence of slip decreased. For this reason, the viscosity measurements were conducted at different rotational speeds. The FSC was prepared and placed on the pot of the viscometer. Pre-mixing was performed by increasing the rotational speed from 0 to 60 rpm in 120 s. As soon as the highest rotational speed was reached, the viscometer stopped. After this initial preparation, a full cycle of increasing rotational speed in eight steps from 0.3 rpm to 60 rpm and back to reset with the same steps was performed. For each rotational speed step, the average of viscosity reading is recorded. This procedure was performed at the beginning (at t = 0 min) and after 20 minutes.[14]

Fig. 3 Mini-slump test for fresh FSC.

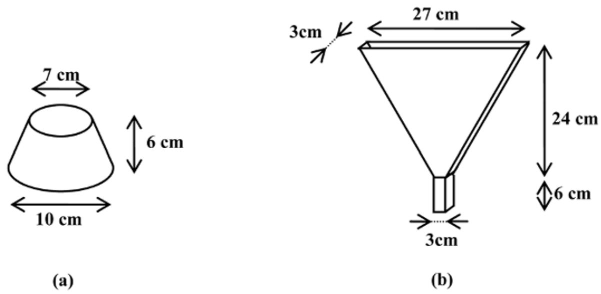

Fig. 4 Dimensions in (cm) of mini-slump cone and v-funnel.

Fig. 5 Programmable DV-II+ viscometer.

Tests for compressive strength of hardened FSC were also conducted. Specimens were cast in stainless steels molds with dimensions of 40 × 40 × 160 mm. The specimens were demoulded one day after casting and were conserved in a water bath under constant temperature. After 28 days of curing the compression tests were carried out.

3. Results and discussions

The influence of DS on compactness of total sand mixture is

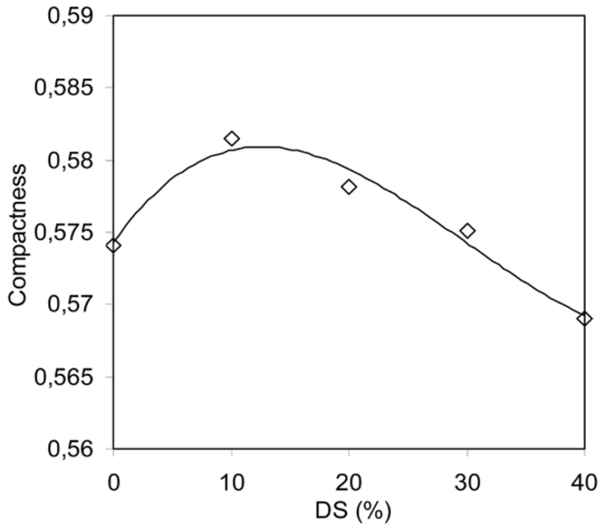

Fig. 6 Evolution of sand compactness in function of DS concentrations.

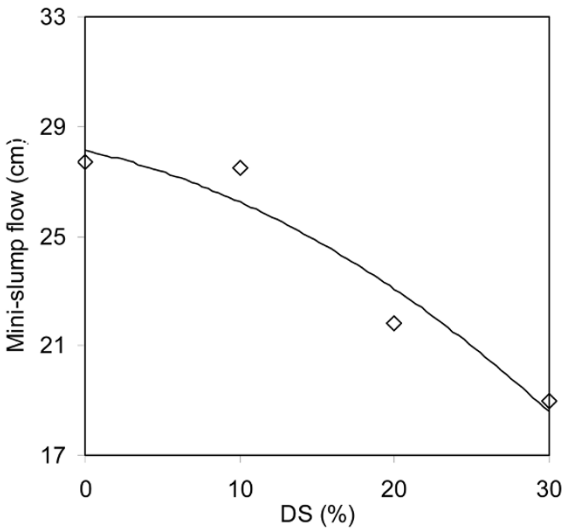

Fig. 7 Effect of DS concentrations on the mini-slump diameter of FSC.

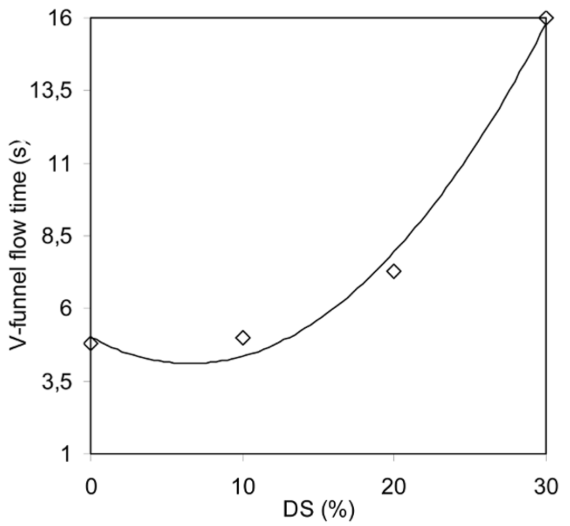

Fig. 8 Effect of DS concentrations on the v-funnel flow time of FSC.

shown in Fig. 6. From these results, it can be observed that by increasing the DS concentration, the compactness increased until a maximum value (around 10%) and then decreased. This can be explained by the filling effect, i.e. before reaching maximum compactness, the fine grains of DS filled spaces between the coarser grains of RS, thereby increasing the compactness of the mixture. Once the voids were completely filled, the fine grains then began to occupy the place of coarser grains, and consequently the compactness of the mixture decreases.

The test results on the effects of DS concentrations on changes in mini-cone slump diameter and v-funnel flow time are illustrated in Figs. 7 and 8 respectively. Results presented in Fig. 7, show that increasing of DS concentration reduced the mini-cone slump diameter. In Fig. 8, results show that the increasing in DS concentration reduced the v-funnel flow time, until a minimum value (between 0 and 10%) before increasing to higher values for 20 and 30% in DS. The decrease in mini-cone diameter and v-funnel flow time is due to the large finesses of DS and to their need for water[15] (Absorption coefficient of DS = 2.18%). The minimum value of v-funnel flow time obtained at 10% of DS is may be due to the higher compactness of aggregate, which results in a smaller volume of void to be filled and hence larger amount of excess paste is gained for lubrication purpose.

The results of viscosity measurements show that the behaviour of all mixes was similar (pseudo-plastic) and can be best fitted with the power-law model (Eq. 2):

$$\mu = a \cdot \gamma^b \qquad (2)$$

Where μ is the viscosity, γ is the rotational speed of mobile part, a and b are constants (called also consistency index and flow index respectively). The coefficients of correlation and constants calculated by using this model are recapitulated in Table 4. Variations in the viscosity of FSC according to the rotational speed and the content of DS are given in Figs. 9 and 10. In general, it was observed that at low rotational speed a viscous behaviour is marked, whereas at high rotational speed a flowable behaviour is governing. It was also observed a viscous behaviour of all FSC mixes with time (at t = 20 min). This result is in agreement with the findings of the other studies reported in the literature.[14,16-19] Figs. 9 and 10 show that there is an optimal DS concentration (at 10%), for which FSC mixes present the lowest viscosities. This is may be a result of the high compactness of aggregates at this concentration of DS, which results in an excess paste for lubrication purpose.[19] The effect of DS was similar after 20 min, with a more

Table 4 Constants (*a* and *b*) and correlation coefficients of the model curves.

Mix N° / Model constants		1	2	3	4
At 0 min	a	23268	20569	37296	34940
	b	-0.6261	-0.5923	-0.6170	-0.6474
	R^2	0.98	0.98	0.99	0.99
At 20 min	a	27309	24785	53499	49427
	b	-0.6076	-0.5807	-0.7091	-0.8371
	R^2	0.98	0.98	0.99	0.99

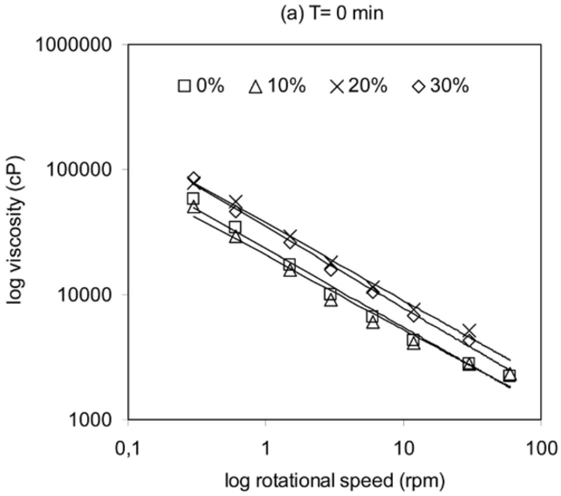

Fig. 9 Effect of DS concentrations on viscosity (at 0 min) of FSC.

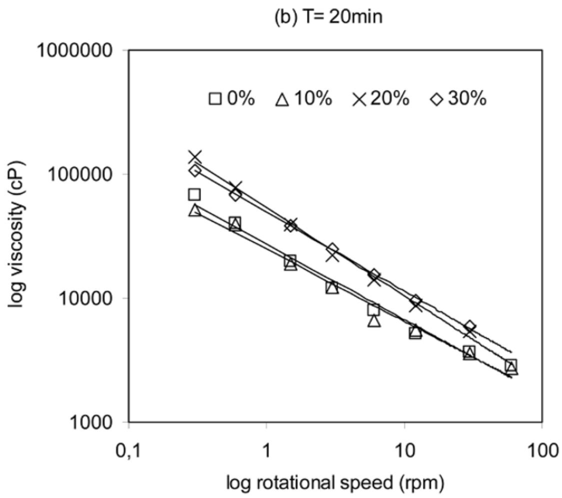

Fig. 10 Effect of DS concentrations on viscosity (at 20 min) of FSC.

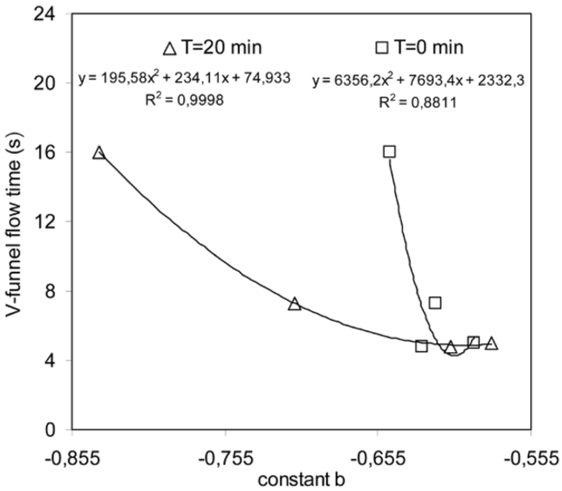

Fig. 11 Correlation between v-funnel flow time and constant *b*.

viscous behaviour of FSC mixes.

Several authors have studied the relationship between v-funnel flow time and viscosity at different rotational speeds. They have concluded that v-funnel flow time correlates in certain cases with the viscosity measurements. In a study on the viscosity of self-compacting repair mortars, Felekoğlu et al.[14] have found that the best correlation between v-funnel flow time and viscosity was derived from the rotational speed 10 rpm. Recently, Güneyisi et al.[17] have found this correlation at 0.5 rpm. As a less sophisticated test, v-funnel flow time correlate in certain cases with some rotational speed of viscometer. However, the coefficients of correlation of the relations seem not very strong and may only reflect the general tendency.[14]

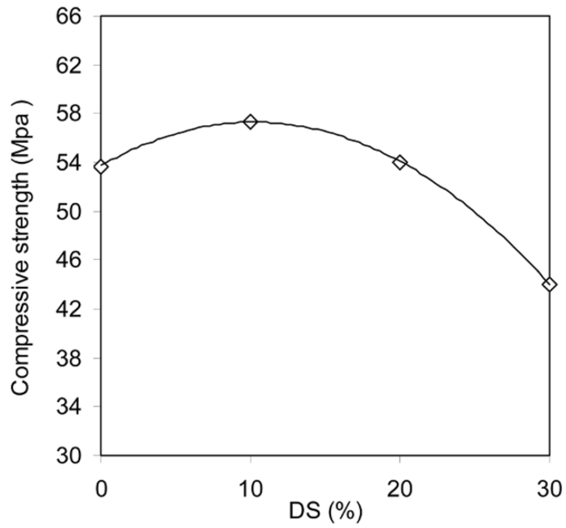

Fig. 12 Effect of DS on 28-day compressive strength of FSC.

The full-log scale representation of viscosity curves depending on rotational speed allows obtaining straight lines (Figs. 9 and 10), where the constant *b* of each curve represents the slope of the corresponding line. The Fig. 11 shows that the constant *b* and v-funnel flow time are best-correlated with good values of coefficients correlation (R^2=0.88 at t=0 min and R^2=0.99 at t=20 min). The correlation results show that when constant *b* increases, v-funnel flow time decreases. In other words, when constant *b* is important for a given mix, lower energy will be necessary to attain flowable consistency.

The compressive strength results of hardened FSC are given in Fig. 12. From these results, it can be seen that the concentration of the DS has an optimal value (about 10%), for which the compressive strength at 28 days is better. This is may be a result of the high compactness of aggregates at 10% of DS.

4. Conclusions

From the findings of this experimental investigation for flowing sand concrete (FSC), the following conclusions can be extracted:

1. Although the sand concrete has been commonly used as a building material since ancient times, recovery of dune sand (DS) remains one of the major problems for the environmental concerns in Saharan regions. However, this study emphasises that this material can be utilized in FSC containing as principal aggregate natural sands.

2. By using DS (around 10% by mass of total sand) with river sand (RS) the compactness of sand grains can be improved.

Thereby, the amount of excess paste can be considerably increased and consequently the fluidity of FSC will be improved. The obtained optimum concentration of DS has allowed achieving FSC mixes with lowest v-funnel flow time and minimum viscosity values.

3. Using the flow index (constant *b*) of best-fitted model curves of viscosity changes depending on rotational speed, the flowability of the mixes can be characterized. In other words, higher is constant *b*, higher will be the flowability. A polynomial relationship between constant *b* and v-funnel measurements, with acceptable coefficients of correlations, were obtained (R^2=0.88 at t=0 min and R^2=0.99 at t=20 min).

4. The optimum concentration of DS (10%), which allows the FSC to have a good fluidity, also allows for better performance in terms of compressive strength at 28 days.

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