The influence of different colours on the mechanical behaviour of quartz sand – first results

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Introduction

Natural quartz sand is the most commonly used granular material in analogue experiments to simulate brittle deformation in the upper crust. It is used in sand packs consisting of alternating layers of coloured sand designed to simulate a rock sequence with constant mechanical properties. The mechanical properties of the natural quartz sand such as cohesion and internal friction have been investigated by e.g. Krantz (1991); Schellart (2000); Lohrmann *et al*. (2003) and Panien *et al.* (2006).

In this study we analyze different coloured quartz sand as well as colourless sand (in the following, these materials are named 'sand types' and 'natural sand', respectively) in order to improve our knowledge of the mechanical behaviour of individual layers of sand packs. We determined the shear stress variations through time of the granular materials using a computer-controlled rotational shear tester, the ring-shear tester RST-XS (Schulze 1994) at the Laboratory of Tectonic Modelling of the Department of Geology, Federal University of Ouro Preto (Brazil). Plots of shear stress as a function of normal stress define Coulomb envelopes that permit to derive the coefficient of internal friction and cohesion from linear regression analysis.

Measurements

For all experiments we used the same moderately-rounded almost pure quartz sand with a grain size spectra between 210 and 350 µm. Tests were performed using mainly sand coloured with a fabric dye (Acrilex) but two colours from a wall dye (Xadrez: blue-X and green-X) were also employed. In order to evaluate the influence of different bulk densities on the friction coefficient and cohesion, material was sifted from heights of 20 cm, 7 cm and 1 cm into an annular cell up to a height of 1,3 cm using a sieve with 350 µm size. Measurements were done for different normal stresses ranging from 800 to 2.400 Pa in steps of 400 Pa and to minimize measuring errors each of the five tests was repeated three times. The experiments were performed to record the mechanical behaviour of sand with the same normal stress in three situations: at peak strength (the onset of failure), at dynamic stable stress (the sliding of the fault) and at second peak strength (the fault reactivation). To evaluate the influence of different grain size on the behaviour of coloured sand we separated the natural sand for one test into two different grain-size fractions before colouring it (210 - 350 µm and < 210 µm).

Results

Shear stress variations through time

Ring-shear test results show that for each sand type the shear stress variations with time are similar for different normal stresses: the shear stress required to attain first peak strength, dynamic stable strength and reactivation peak strength strongly increases with normal stress increase. However, the curves change between different sand types (compare figures 1A and B; and see figures 1C and D). In figures 1C and D the only exception is the yellow sand behaviour, very similar to the blue sand. Black and green sand types are also very similar to the blue sand mechanical behaviour, but are not shown. Under the same normal stresses natural, blue and red sand types (Fig. 1C) and natural, blue and blue-X ones (Fig. 1D) show different strain softening rates and failure at peak strength at different times.

Finally, shear stress curves illustrated in figures 1E and F reveal that neither the sifting height nor the grain size influence the blue/black sand behaviour. Only natural and red sand reveal small variations (not shown).

Internal friction and cohesion

Table 1 reveals that with exception of the blue Acrilex sand types the angles of peak friction vary strongly. The highest values are shown by the red sand (44,54°) followed by the blue-X (43,08º) and green-X (42,92º) types and the natural one sifted from 7 cm height (42,27º). The lowest values of peak friction are shown by the blue Acrilex sand types, which in turn also show the smallest difference between 1º and 2º peaks. Figure 1F reveals for the black sand a higher 2º peak then for the first one.

A unique relationship between angle of peak friction and bulk density is shown by blue Acrilex and yellow sand types. These sand types show relative low angle of peak friction (blue sand = 38,97º, 39,49º and 38,55º; yellow sand = 37,85º) and low bulk density (blue sand = 1,06 g/cm^3, 1,05 g/cm^3, and 1,10 g/cm^3; yellow sand = 1,05 g/cm^3). Natural quartz sand (sieved from three different heights) has the highest bulk density (1,54 g/cm^3, 1,52 g/cm^3 and 1,54 g/cm^3), but in this case bulk density does not relate to the angle of peak friction.

At the stress range tested in our experiments, cohesion is low, varying between 36,3 Pa and 154,5 Pa, and are in good agreement with those described in literature (Lohrmann *et al*., 2003; Panien *et al*., 2006).

Table 1. Sifting heights, bulk densities (*) and mechanical properties of different coloured and natural sand measured with a ring-shear tester RST-XS (Schulze 1994). Blue-X and green-X represent the Xadrez dyes; all the other colours are Acrilex dyes. R^2 is the square of the correlation coefficient in the linear regression method (values close to 1 indicate excellent linear reliability).

colour	sifting height (cm)	ρ (*) (g/cm^3)	Φ (°) 1º peak	C (Pa) 1º peak	Φ (°) 2º peak	C (Pa) 2º peak	Φ (°) stable.	C (Pa) stable
natural	20	1,54	38,63 R^2 = 0,9589	129,9	32,90 R^2 = 0,9742	131,3	31,67 R^2 = 0,9777	78,6
blue	20	1,06	38,97 R^2 = 0,9951	116,9	37,49 R^2 = 0,9956	103,2	35,45 R^2 = 0,9975	87,8
blue-X	20	1,26	43,08 R^2 = 0,9909	64,8	36,92 R^2 = 0,9966	89,6	34,73 R^2 = 0,9962	70,6
green-X	20	1,34	42,92 R^2 = 0,9964	81,4	36,32 R^2 = 0,9959	103,2	33,90 R^2 = 0,9966	91,4
natural	7	1,52	42,27 R^2 = 0,9969	36,3	34,64 R^2 = 0,999	105,4	32,29 R^2 = 0,999	98,4
blue	7	1,05	39,49 R^2 = 0,976	108,3	38,55 R^2 = 0,9965	77,0	36,76 R^2 = 0,9968	65,4
red	7	1,21	44,54 R^2 = 0,9956	36,7	38,76 R^2 = 0,9951	90,3	36,17 R^2 = 0,9947	78.8
yellow	7	1,05	37,85 R^2 = 0,996	117,8	37,60 R^2 = 0,998	91,7	36,46 R^2 = 0,994	60,1
natural	1	1,54	38,67 R^2 = 0,9737	154,5	33,80 R^2 = 0,9956	101,8	32,04 R^2 = 0,9923	71,9
blue	1	1,10	38,55 R^2 = 0,991	129,8	38,27 R^2 = 0,9967	91,1	36,28 R^2 = 0,9983	68,3

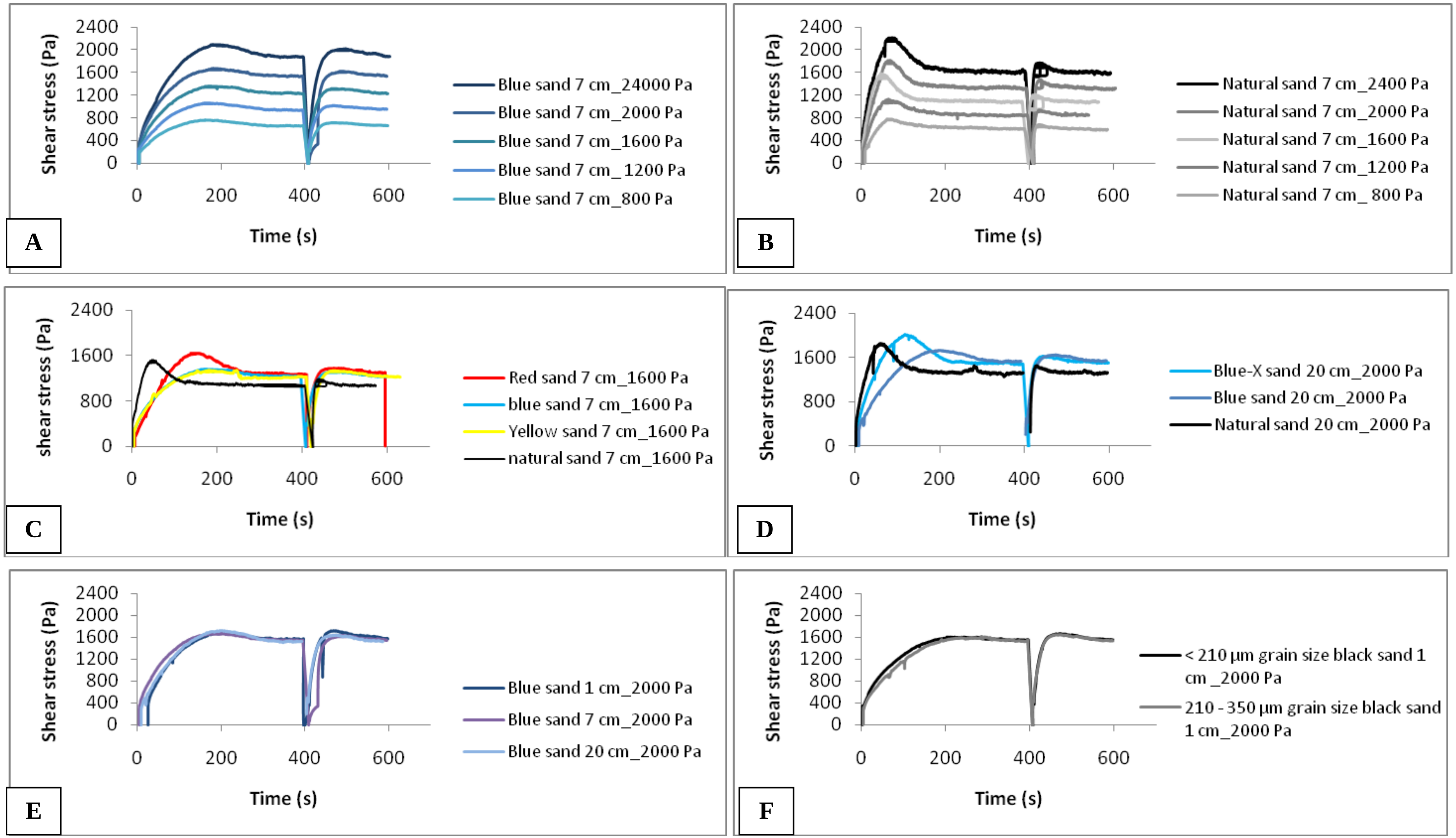

Figure 1. Plots of shear stress as a function of time for (A) blue sand sieved from 7 cm height at different normal stress; (B) natural sand sieved from 7 cm height at different normal stress. (C) red, blue, yellow and natural sand types sieved from 7 cm height at the same normal stress of 1600 Pa; (D) blue-X, blue and natural sand types sieved from 20 cm height at the same normal stress of 2000 Pa; (E) blue sand sieved from different heights (20 cm, 7 cm and 1 cm) at the same normal stress; (F) different grain size black sand sieved from 1 cm height at the same normal stress of 2000 Pa. Blue-X sand is sand coloured with wall dye (Xadrez); the other sand types were coloured with fabric dyes (Acrilex).

Conclusions

Our analysis of the mechanical behaviour of different coloured sand reveal that the most important control over the frictional properties of sand is related to the colours used to dye it. Neither sand bulk density nor sifting heights or grain size play an important role in our analysis but we observed that the different dyes produced a high variation of the peak friction angle. Although our values of peak friction angle are high (varying from 37,85° to 44,54°), they are in the range of values reported by Rossi & Storti (2003) (between 24,2° to 42,0°).

New tests must be done to provide insights to questions, such as: why shear stress variations with time are so different for the coloured sand types tested? why natural sand tested at three different sieving heights presents the highest peak friction at 7 cm height? why red sand show the highest angle of friction, even higher than the natural one?

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