# MAGNESIUM OXIDE AS ALTERNATIVE BINDER FOR UNFIRED CLAY BRICKS MANUFACTURING

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## ABSTRACT

Replacement of fired bricks by unfired ones could be an effective way to reduce the building industry environmental footprint: Their manufacture not only requires less energy and natural resources but also generates less waste. Bricks are based on the use of an additive cementitious material in the form of a binder, usually lime or cement. Such additives have a great environmental impact owing to the high energy consumption and $CO_2$ during in their manufacturing process. In this article experiments are carried out in order to investigate the applicability of a MgO rich industry by-product as a binder for the production of unfired clay bricks. From the experiments, the MgO was observed to show ability to enhance the mechanical properties of a clay brick in much the same way as lime does. Water absorption tests on bricks revealed the superiority of MgO over lime in enhancing the durability properties of unfired bricks. The laboratory results demonstrate the high potential of MgO based additives as alternative binders to the calcium based ones. Consequently, this offers opportunity for reducing the environmental impact associated with the use of fired clay bricks. In addition, it could allow an effective way for the valorization of MgO containing industry by-products that currently discarded to landfills.

## KEYWORDS

Magnesium oxide; lime; unfired clay bricks; pozzolanic reactions; mechanical properties; durability.

## 1. INTRODUCTION

Fired clay bricks are used extensively for buildings construction around the world. The use of these bricks entails the consumption of large amounts of energy, with the manufacturing process requiring around 4186.8 MJ/tone, mainly due to the firing process involved (BDA, 2010). The achievement of environmentally cleaner and a more sustainable building industry is an increasing concern, having become a major social and governmental goal for the sector (European Commission, 2014). Accordingly there is a challenge to develop more environmental friendly building materials such as unfired bricks. Such products can replace fired bricks in many applications, with considerable reductions in energy usage, natural resource consumption, and in the amount of wastes dumped in landfills (Oti et al., 2009). Unfired bricks are made up of t clay soil and a binder, which is usually lime or cement. Pozzolanic reactions between the clay and the binder result in transformation of the mechanical strength and durability properties of unfired bricks, making them suitable to be used as construction material (Seco et al., 2017).

From an environmental viewpoint, the use of calcium based additives like lime or cement inevitably leaves environmental footprint: because of the manufacturing necessitates de carbonation of natural rocks to convert $CaCO_3$ into CaO. This process releases large amounts of $CO_2$ and requires a high energy consumption (Damtoft et al., 2008; Bellman and Stark, 2009; Habert el at., 2011).

From a chemical point of view certain attributes of MgO are similar to CaO. It has been stated (Xeidakis, 1996a; Xeidakis, 1996b) that MgO has the ability to flocculate clay soils, leading to formation of cementitious gels. Additionally, Seco et al. (2011) reported that MgO reduced the natural swelling potential of expansive soils and other researchers (García et al., 2004; Navarro et al., 2006; Del Valle et al., 2015) reported the ability of MgO to immobilize heavy metals in contaminated soils. These researches show the potential of Mg based binder as alternative to Ca based ones. Magnesite is an essential material for the manufacturing of refractory products. It is obtained by the calcination of raw $MgCO_3$ rocks at 1,100º C. Under these conditions the natural mineral decarbonates and turns into a MgO vitrified matrix. Industrially, this process is carried out in rotary kilns with crosscurrent air. As the air moves, it pulls dust from the whole length of the kiln containing three chemicals: (i) inert $MgCO_3$ particles, (ii) reactive, calcined MgO particles and (iii) inert vitrified MgO particles. In Spain, the production of calcined magnesite is approximately 150,000 tons per annum, generating 50,000 tons of kiln dust per year. The annual consumption of the product is however much less and the excess production ends up in landfills, thereby causing significant economic, social and environmental concerns.

This research continues the work of Miqueleiz et al. (2012) who studied the stabilization of a Spanish Clay soil with different binders. In this context, this investigation analyzes the ability of the magnesium-based additives to substitute for the calcium-based ones for a more sustainable building material. Thus it was imperative to how differently the additions of MgO rich dust and lime influence the properties of unfired clay bricks, in terms of mechanical strength and durability.

## 2. MATERIALS

For this research a sample of a locally sourced clay soil was used. A detailed description of this soil can be read in Miqueleiz et al., (2012).

TABLE 1

Table 1 shows the mineralogical composition of the clay sample as measured by XRD analysis, based on the chart proposed by Al-Rawas (1999). From a mechanical point of view, according to the Spanish Standards UNE 103104 and UNE 103103, this material showed a plastic limit (PL) of 24.9% and a liquid limit (LL) of 43.5%. Based on the Standard Proctor compaction Test (SP), as defined in the standard UNE 103500, the maximum dry density and the optimum moisture content were found to be 1.76 Mg/m$^3$ and 15.4%, respectively. The swelling potential of the soil, based on the standard UNE 103601, was 3.88%.

Two different binders were used in this study: (1) a sample of a MgO rich kiln dust named PC-8, produced by Magnesitas de Navarra S.A. Company in its factory located in Zubiri (Navarra, Spain), and (2) a commercial calcareous hydrated lime (CL-90-S), complying with the Spanish Standard UNE-EN 459-1. Table 2 shows the composition of both additives, expressed as their most significant oxides, based on XRF analysis.

TABLE 2

## 3. METHODOLOGY

To test the effectiveness of both additives, mechanical properties and durability were investigated for the 12 different dosages shown in Table 3.

TABLE 3

The codes used for the different combinations are composed of the binder identification "PC-8/" in the case of the MgO waste and "CL-90/" in the case of the lime, followed by the percentage of additive. These applied dosages exceed the usual range of 4-10% but this was intended to enable analysis of the effects of the deficiency or overdose of the additives on the resulting properties of unfired bricks. A similar strategy was used successfully by Miqueleiz et al. (2012).

The mechanical properties of the unfired clay bricks were measured through unconfined compressive strength tests performed, in accordance with the Spanish standard UNE 103400. Durability properties were assessed through measuring the water absorbed by the bricks after 24 hours of immersion in water, as stipulated by the European Standard EN 771-1. The unfired brick specimens were prepared as follows:

a) For each combination clay soil and additive, Moisture/Density curves were calculated following the procedure showed in Seco et al. (2017), based on the Spanish Standard UNE 103500. This allowed determination of the Optimum Moisture Content (OMC) necessary to achieve the Maximum Dry Density (MDD) for the 13 N/mm$^2$ compaction pressure applied.

b) For each clay-additive combination, enough quantities of the dry soil and additive were poured in a laboratory mixer and mixed thoroughly for 10 minutes to be as homogenous in state as possible.

c) Then a calculated volume of water was added to the mix to achieve the OMC. The ingredients were then thoroughly mixed for a further 10 minutes to a uniform state.

d) The wet mix was then compacted in a 65 mm diameter by 75 mm high cylindrical mold, using a 5 kN hydraulic press. After compaction the specimens were demolded and stacked in a wet chamber for curing, covered with polythene sheeting to prevent further moisture losses.

e) The samples were cured for 1, 7, 28, 56 and 90 days to reach the intended testing age. In this research, a total of 360 cylindrical specimens corresponding to the 12 soil-additives combinations, were prepared.

## 4. RESULTS AND DISCUSSION

### 4.1. MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE CONTENT DETERMINATION

Figures 1 and 2 show the MDD and the OMC variations for the different combinations.

FIGURE 1

FIGURE 2

The addition of PC-8 to the soil from 3% to 18%, produced a slight increase of MDD from 1.98 g/cm$^3$ to 2.00 g/cm$^3$ and an increase of OMC from 12.6% to 15.7%. The addition of lime to the RC soil decreased the MDD, from 1.89 g/cm$^3$ to 1.80 g/cm$^3$. With this additive OMC rose from 13.1 % to 18.3 %.

### 4.2. UNCONFINED COMPRESSIVE STRENGTH

Figures 3 and 4 show the unconfined compressive strength results of PC-8 and CL-90-S combinations, after 1, 7, 28, 56 and 90 days of curing time.

FIGURE 3

FIGURE 4

Generally, for all curing periods, specimenPC-8 showed clearer differences in unconfined compressive strength than those containing lime.

There compressive strength of PC-8 increased continuously for dosages up to 15%, reaching a maximum value of 9.9 N/mm$^2$ at 90 days. It decreased slightly for 18% dosage, showing a saturation of the additive and a counterproductive effect of the highest PC-8 percentage combination. On the other hand, the unconfined compressive strength of CL-90-S attained a maximum value of 9.8 N/mm² at 90 days. The aforementioned maximum strength value was shown by the 6% combination specimen. For higher percentages of lime at all curing times, the strength decreased more markedly for 12% and higher additive percentages.

## 4.3. RATE OF WATER ABSORPTION

Figures 5 and 6 show the water absorption test results at 7, 28, 56 and 90 days of curing time.

FIGURE 5

FIGURE 6

All the specimens with 3% of both additives, as well as the combination of 6% PC-8, collapsed when immersed in water, regardless of the curing time. In addition, all the CL-90-S specimens tested at 7 days also collapsed when immersed in water. The other combinations showed an improved behavior of decreasing water absorption as both additives dosages increased with increasing curing time. In this test no counterproductive effect of an excess of both additives was observed.

In the case of the PC-8 combinations, the effectiveness starts at the age of 7 days, with a minimum dosage needed of 9%. PC-8 samples showed small water absorption differences and a homogeneous behavior until 56 days of age, when the range was 9.92-10.70. The water absorption values decreased significantly at 90 days when combinations with 12, 15 and 18% of PC-8 reached values about 5%, being the smallest 4.9% for the 18% of this additive. Only the 9% combination showed a different behavior with a final water absorption of 8.1%.

In the case of the lime, the effectiveness starts at the age of 28 days of curing time. A minimum dosage of 6% was needed for the stability of the samples. At the age of 56 days there were observed significant differences of water absorption between, by one side, the combinations containing 6% and 9% of lime, with 12.9% and 12.7% of water absorption respectively and, by other side, the combinations of 12%, 15% and 18% lime, with 9.2%, 8.5% and 7.5% of water absorption, respectively. This trend was also observed at 90 days when the combination with 18% of lime reached the lowest water absorption value, 5.1%.

## 5. CONCLUSIONS

The results obtained in this research suggest that there is potential in using magnesium oxide based additives like PC-8 as unfired clay brick manufacturing binder. The performance of the PC-8 treated samples can be compared with the lime treated ones, based on the characteristics of the properties analyzed: mechanical strength and durability.

From a mechanical point of view, the properties of the PC-8 combinations were similar to the samples treated with lime at the usual additives percentages in the production of unfired clay bricks (4-10%). PC-8 samples showed a lower resistance than lime ones at the lowest dosage percentages, reaching better values for the highest binder contents. In the case of lime a counterproductive effect, clearer than in PC-8, was observed because of the excess of additive, even for relatively low percentages.

Considering the durability point of view, the water absorption for both additives decreased as their dosage increased, being more effective and earlier in the case of the

PC-8 than in lime samples, although this additive required a higher minimum dosage. These results agreed with the behavior observed in the mechanical test results, where higher PC-8 contents allowed better resistances.

These results state the suitability of the magnesium oxide as additive for the production of more sustainable and with high performance construction materials. In addition it can be a way for the valorization of MgO containing byproducts.

## 6. ACKNOWLEDGEMENTS

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## 8. FIGURES

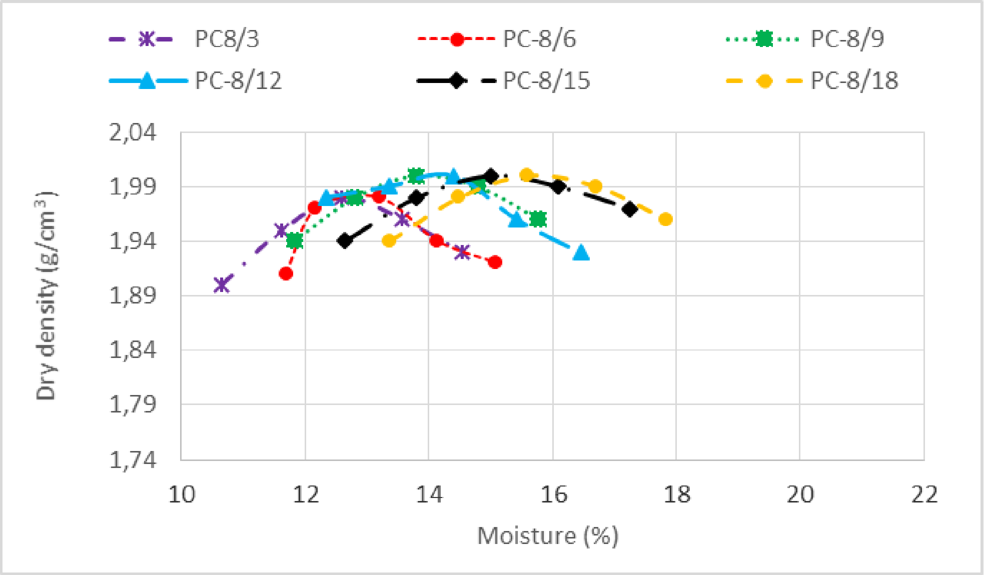


Figure 1. Optimum Moisture Content and Maximum Dry Density of the PC-8 combinations.

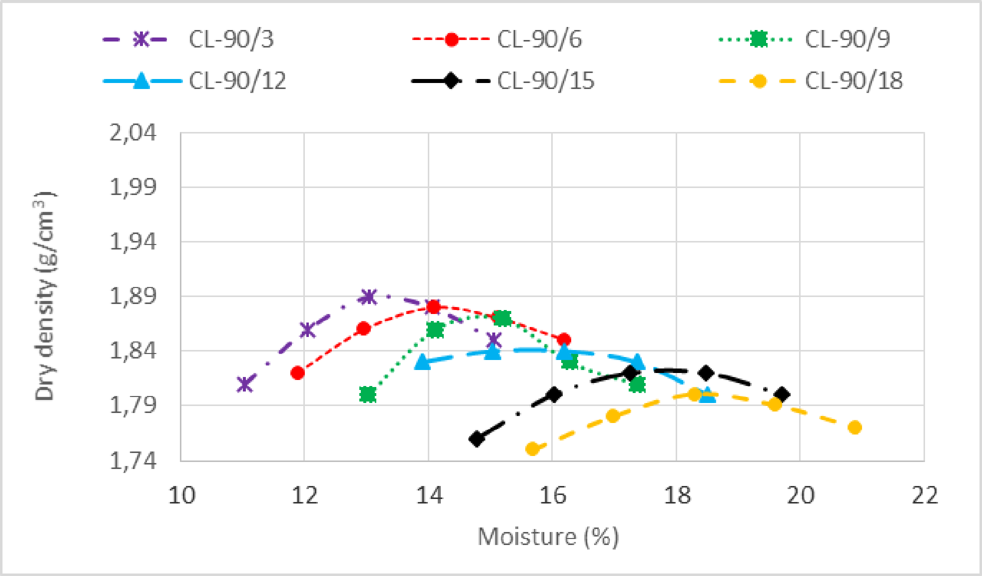


Figure 2. Optimum Moisture Content and Maximum Dry Density of the CL-90-S combinations.

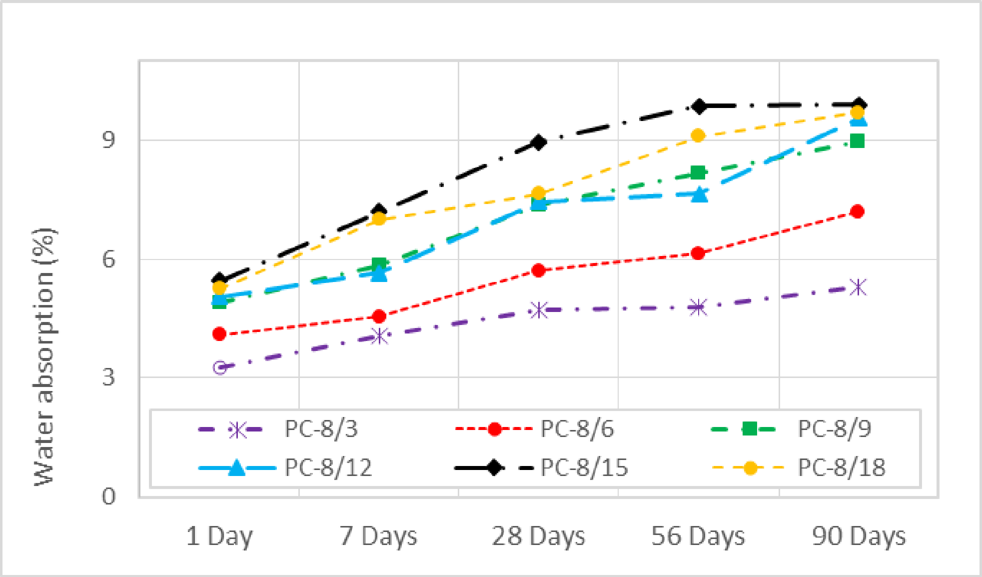
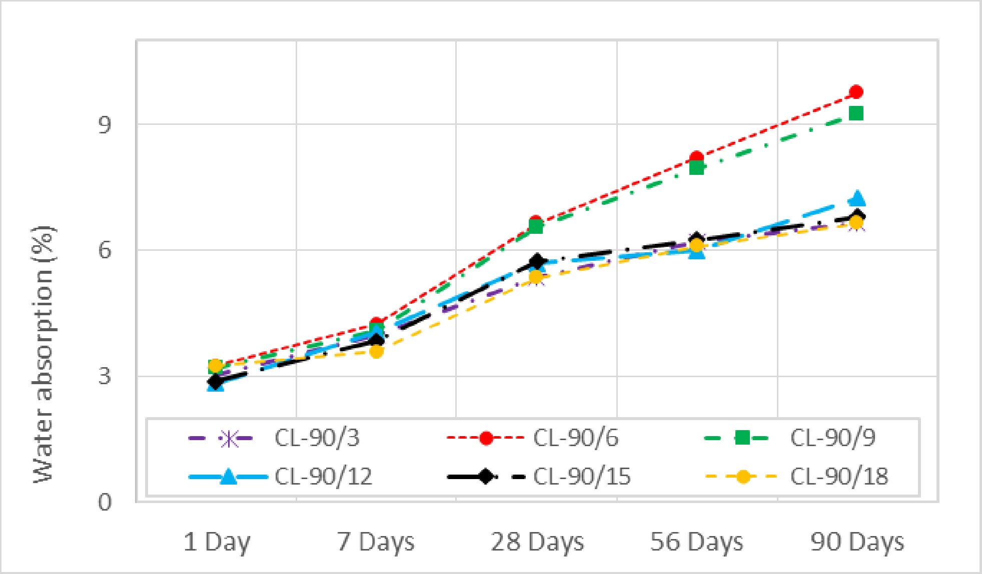


Figure 3. Unconfined Compressive Strength of the PC-8 samples at the different curing ages.



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295 Figure 4. Unconfined Compressive Strength of the CL-90-S samples at the different

296 curing ages.

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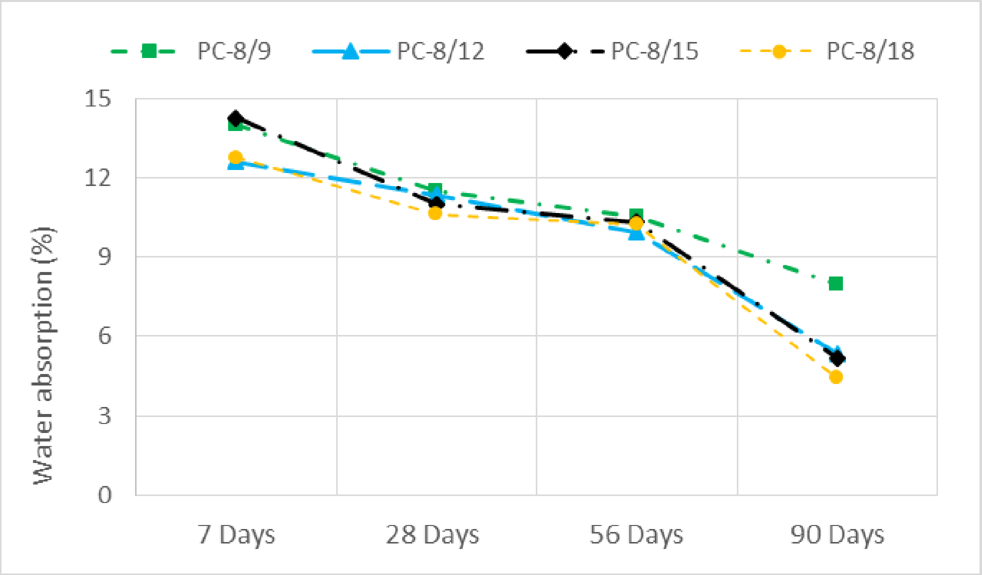

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300 Figure 5. Water absorption of the PC-8 samples during the testing period.

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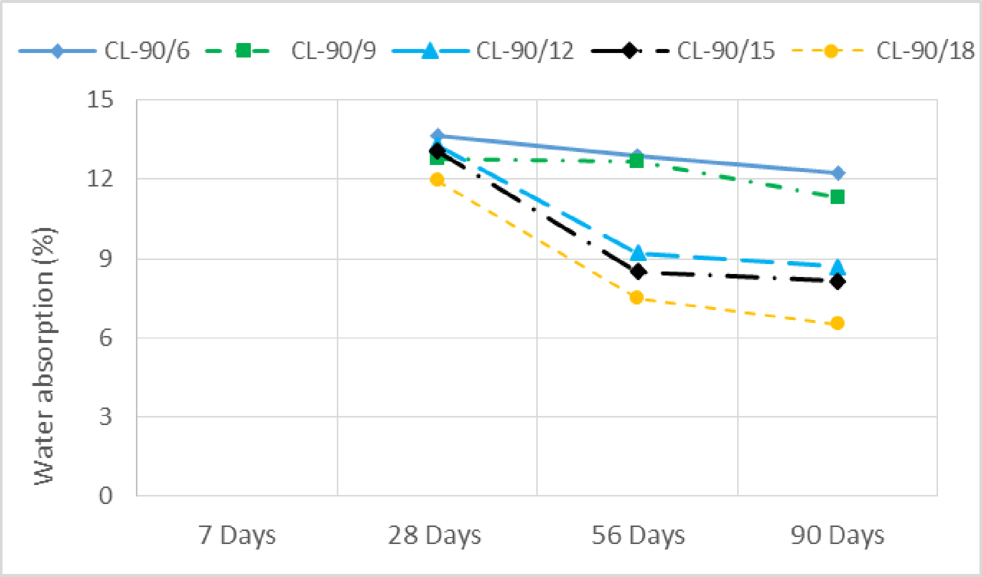

Figure 6. Water absorption of the CL-90-S samples during the testing period.

## 9. TABLES

**Table 1.** XRD-based mineralogical composition of the Red Clay soil.

| **Mineral** | **Composition (%)** |
|---|---|
| Quartz | 31 |
| Calcite | 30 |
| Muscovite | 17 |
| Dolomite | 12 |
| Chlorite | 6 |
| Gypsum | 4 |

**Table 2.** Oxide composition of the additives.

| **Oxides (%)** | **PC-8** | **CL-90-S** |
|---|---|---|
| $Ca(OH)_2$ | - | >95 |
| CaO | 7.40 | |
| MgO | 61.85 | |
| $SO_3$ | 7.26 | |
| $Fe_2 O_3$ | 2.42 | |
| $Al_2 O_3$ | 0.56 | |
| $SiO_2$ | 3.41 | |

**Table 3.** Additive dosages tested.

| CODE | DOSAGE OF PC-8 (%) | DOSAGE OF CL-90-S (%) |
|---|---|---|
| SOIL | - | - |
| PC-8/3 | 3 | |
| PC-8/6 | 6 | - |
| PC-8/9 | 9 | - |
| PC-8/12 | 12 | - |
| PC-8/15 | 15 | - |
| PC-8/18 | 18 | - |
| CL-90-S/3 | - | 3 |
| CL-90-S/6 | - | 6 |
| CL-90-S/9 | - | 9 |
| CL-90-S/12 | - | 12 |
| CL-90-S/15 | - | 15 |
| CL-90-S/18 | - | 18 |