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PETROGRAPHIC EVALUATION OF A 50-YEAR-OLD CONCRETE PAVEMENT MADE WITH QUARTZITIC AGGREGATE

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Abstract

A 50-year-old pavement from the city of La Plata (Province of Buenos Aires, Argentina), which had recently been replaced due to significant deterioration (cracks, sinking, etc.), was examined. The aim of the present work was to conduct a petrographic analysis of the concrete, in order to identify the causes leading to pavement failure. Petrographic studies were performed on two slabs and thin sections (ASTM C 856). The coarse and fine aggregate characteristics, the mortar and the paste–aggregate interface were examined, and the reaction products were analysed by XRD and SEM–EDS. The coarse aggregate is an orthoquartzite composed of angular quartz, with some particles exhibiting undulatory extinction, rare argillaceous matrix and microcrystalline siliceous, micaceous and/or ferruginous cement. The fine aggregate is natural siliceous sand. Commonly unfilled microcracks in the mortar and in some interfaces, as well as carbonated zones, were observed. Ettringite in entrained air voids was identified by XRD and SEM–EDS. No evidence of deleterious reaction development (e.g. ARS) was found. Concrete failure was attributed to high heavy traffic as it is an access area to La Plata port and the city.

1. INTRODUCTION

The present work addresses petrographic aspects related to the durability of a concrete pavement that was in service for 50 years in order to evaluate its long service life. The aspects considered are the aggregate type and composition, mortar (sand and cement paste) characteristics and the paste–aggregate interface, as well as the composition of reaction products filling entrained air voids and microcracks.

The pavement under study consisted of a three-component system: (i) a sub-base made of a compacted fine granular material, (ii) a concrete base and (iii) a high-quality concrete surface

slab. Before its removal, the surface slab was affected by transverse and longitudinal cracks, erosion at joints and edges, and faulting (Fig. 1a).

Aggregates play a key role in the new conception of structures, where sustainability should be a major priority from the start of the project to the end of its service life and subsequent recycling [1]. A classic definition of sustainable development is the one formulated in 1987 by the United Nations World Commission on Environment and Development (WCED): *“development that meets the needs of the present without compromising the ability of future generations to meet their own needs* [1-2]. The manufacturing process of cement, the intensive use of industrial waste and the construction process play a key role in concrete performance. The possibility of designing and building more durable structures makes us think that in the future the strength and durability properties of concrete will have to be improved, so it will be necessary to conduct deeper studies on the concretes manufactured up to date, evaluate their properties, and investigate new materials and construction methods.

Long-life concrete pavements are those that provide between 30 and 60 years of service life and require less maintenance and rehabilitation. Moreover, long-life concrete pavements minimize traffic disruptions, user costs, life cycle, and increase safety. The quality of materials, a good mixture design and the structural design are of outmost importance. For the pavements, the factors to consider are: slab thickness (not less than 30 cm), type of base or sub-base/drainage, the design of joints and the treatment of edges [3].

The main faults of rigid pavements are longitudinal and transverse cracking (due to different causes), erosion due to pumping and faulting [4]. External and environmental attacks, as well as internal deleterious reactions, which in some cases are influenced by environmental conditions such as moisture and temperature, should also be considered. The last two factors depend on the environment and the site where the structure is placed, and contribute to the development of the alkali–silica reaction (ASR) that in most cases leads to specific crack patterns and other associated pathologies [5].

Cracks may have different origins or causes: fatigue, reflection of joints or cracks from underlying layers or adjoining slabs, loss of support due to erosion and/or differential settlement. The internal (ASR) and external deleterious reactions (sulphate and chloride attack, etc.) may also lead to significant cracking. The erosion due to pumping and faulting are caused by the movement of water (with suspended material) accumulated beneath the slab or its ejection towards the surface due to pressure generated under the action of loads. So, a base/sub-base is required whenever this risk exists and under different simultaneous conditions such as repeated heavy loads (lorries) causing deflections at joints and pavement edges, the presence of water at the slab–sub-base/base–hard shoulder interface or a subgrade of fine-grained soils that can be forced out carrying soil particles in suspension [4].

Based on the above considerations, it is necessary to take these aspects into account and relate them to petrographic observations in order to evaluate and justify what characteristics made the concrete studied in the present work have a long service life and what factors determined the end of its service life.

The objective of the present work was to conduct a petrographic analysis of the concrete to identify the causes leading to pavement failure.

2. MATERIALS AND METHODS

2.1 Materials

The concrete pavement studied had been removed to carry out repavement works on several sections of a main avenue in the city of La Plata (Province of Buenos Aires, Argentina) (Fig. 1b), with intense heavy traffic (lorries), which provides access to the city and the port area, and also connects with a provincial coastal route. It was affected by cracks in several directions, faulting and erosion at joints and edges (Fig. 1a). It consisted of a sub-base of compacted fine granular material, a medium-quality concrete base, and a high-quality concrete surface slab.

The concrete from the base and surface slab was studied, considering the differences between them as they had been subjected to different load distributions and different micro-environmental conditions.



Figure 1: (a) Pavement affected by longitudinal and transverse cracks, slab sinking and joint faulting. (b) Removal of concrete slabs (sampling area).

The samples taken from the base slab contained no reinforcements and their average thickness was 13 cm (Fig. 2a). The concrete from the surface slab contained remnants of dowels and tie bars, and was about 20 cm thick (Fig. 3a).

2.2 Methods

The concrete microstructure and reaction products were studied by conventional and detailed supplementary methods specified by ASTM C 856 [6]. An Olympus (SZ61) stereomicroscope was used for small concrete samples and an Olympus (BH2-UMA) polarizing optical microscope for thin sections.

Concrete samples with pores filled with reaction materials were used for SEM–EDS studies. These materials were collected from some of these pores to be analysed by XRD. To identify the reaction products, a JEOL JSM 35 CP scanning electron microscope (SEM), coupled to an energy dispersive spectrometer (EDS) for qualitative elemental microanalysis on carbon-metallised samples, was used. Samples were analysed by X-ray diffraction (XRD) using a Rigaku D-Max III-C diffractometer, operated at 35 kV and 15 mA, with a copper anode and a curved graphite monochromator, with a 0.04 step and a counting time of 1 second per step.

3. RESULTS

3.1 Stereomicroscopy

Base slab concrete: remnants of a granular sub-base slab consisting of cement-treated crushed quartzitic sand were adhered to the lower surface. This contact area was in very good condition.

The concrete is composed of a crushed quartzitic coarse aggregate ranging between 2 cm and 5 cm in size and a mortar consisting of abundant natural siliceous fine aggregate. The cement paste is light grey with pale yellowish micro-areas. Mortar pores vary in size and morphology and are mostly filled with fibrous and irregular crystalline masses of white tinge and pearly lustre.

The quartzitic aggregates have all the characteristics of *piedra Mar del Plata* (Mar del Plata stone), which is exploited in the town of Batán, close to the coastal city of Mar del Plata (Argentina). Most of the particles are inequidimensional and occur in elongate, triangular or flaky forms; they are white-greyish and some of them have a yellowish and reddish-pink tinge. Quartzite is composed of more than 95% of angular to subangular quartz, the grain size ranges from thick (greater than 2 mm) to fine, and the intergranular spaces may be empty or filled with a very fine white or yellowish material due to the presence of clays or microcrystalline quartz and/or iron oxyhydroxides. These rocks also contain a small percentage of tourmaline, mica and other mafic minerals' grains. Other aggregate fragments may consist of quartz micaceous wackes and clays that occur in lower percentages.

The mortar characteristics are very good, although it may be partly affected by cracks, which sometimes may also affect the interfaces with the coarse aggregate. Although the cracks are cohesive and in good condition, voids or irregular pores many millimetres in size and circular pores less than 1 mm in diameter, mostly filled with whitish products, are commonly seen (Fig. 2b and 2c). Such products occur as masses or fibrous crystals of pearly lustre that would be associated with ettringite (Fig. 2d).

Surface slab concrete: it has similar characteristics to those of the base slab. The coarse aggregate is composed of the same quartzite and the mortar has similar proportions of fine aggregate and cement paste. Differences were found at this scale, namely that almost all the cement paste is yellowish grey due to the carbonation process (Fig. 3a) and the pores and entrained air voids are not filled or their walls are visibly lined. The coarse aggregate–paste interface is in good condition, with no cracks.

In general, the state of conservation of the concretes examined by this technique is good, as shown in Fig. 2 and 3.

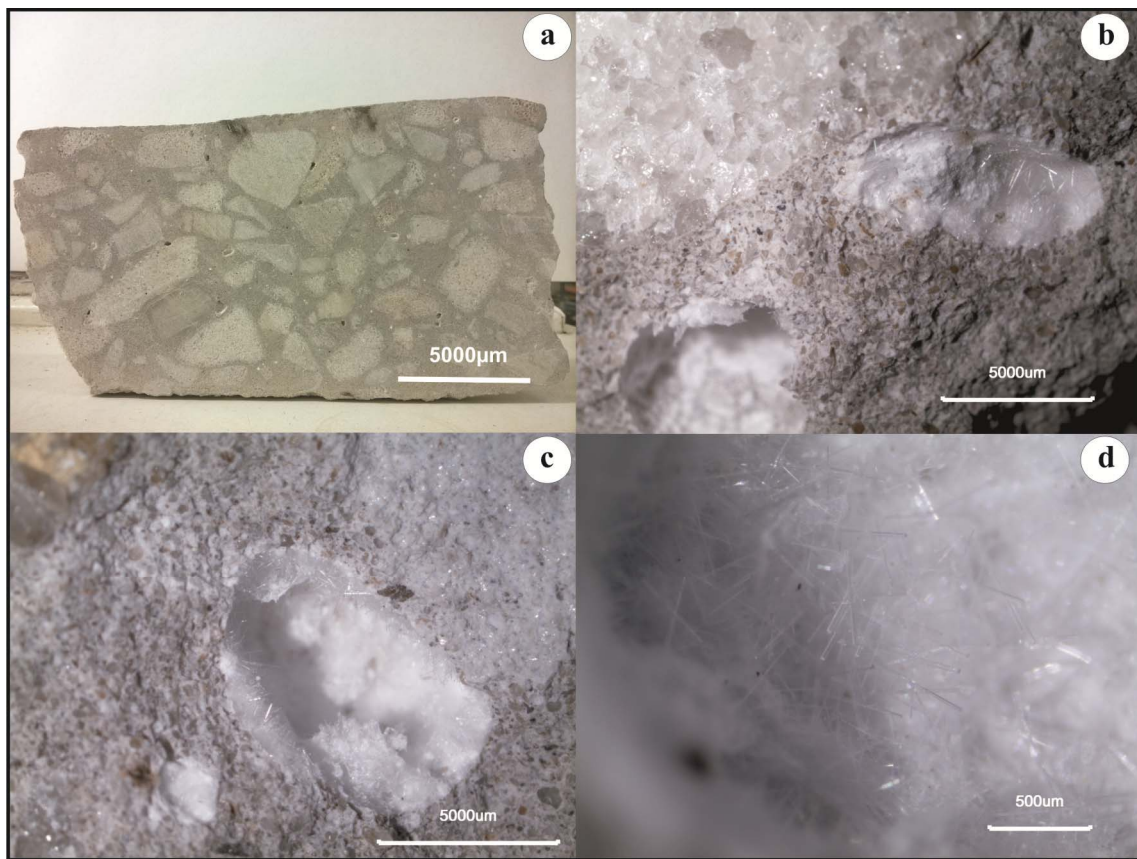


Figure 2: Base slab concrete. (a) Mesoscale image showing the total slab thickness where the quartzitic coarse aggregate and the mortar with entrained air voids can be seen. Images (b), (c) and (d) taken with a binocular magnifier. (b–c) Detail of mortar pores, close to the interface with the quartzitic coarse aggregate, filled with a reaction material. (d) Detail of the reaction material, which is crystalline and of acicular habit.

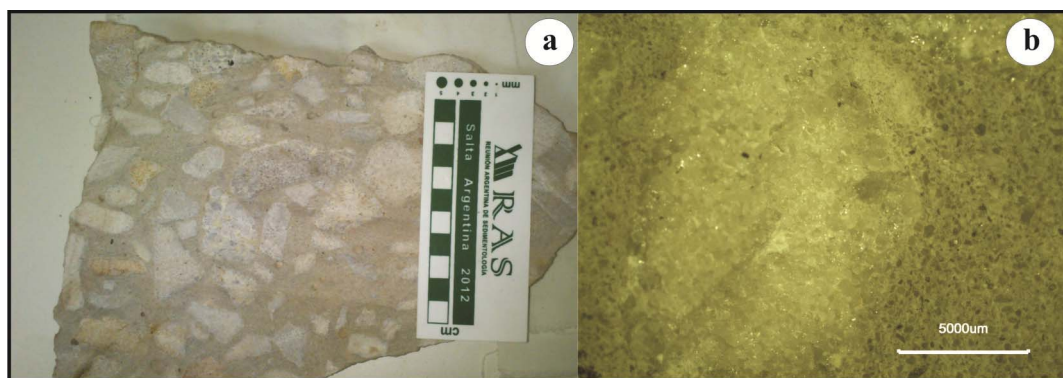


Figure 3: Surface slab concrete. (a) Mesoscale image. The total thickness cannot be seen. (b) Binocular magnifier image showing a whitish quartzitic coarse aggregate, the yellowish grey mortar and the interface, which are in good condition.

The surface slab concrete is similar to that of the base slab. As shown in Fig. 4e and 4f, the coarse aggregate–cement paste interface is in good condition, cohesive and with good adhesion, but in some cases microcracking and carbonation were observed in the area of the coarse aggregate–mortar interface, as well as some entrained air voids partially filled with calcite, portlandite and/or ettringite, as shown in Fig. 4g and 4h. Close to the microcracks and voids, the mortar is carbonated, and portlandite crystals that may form a kind of halo around the aggregates, mainly the fine aggregate, are common.

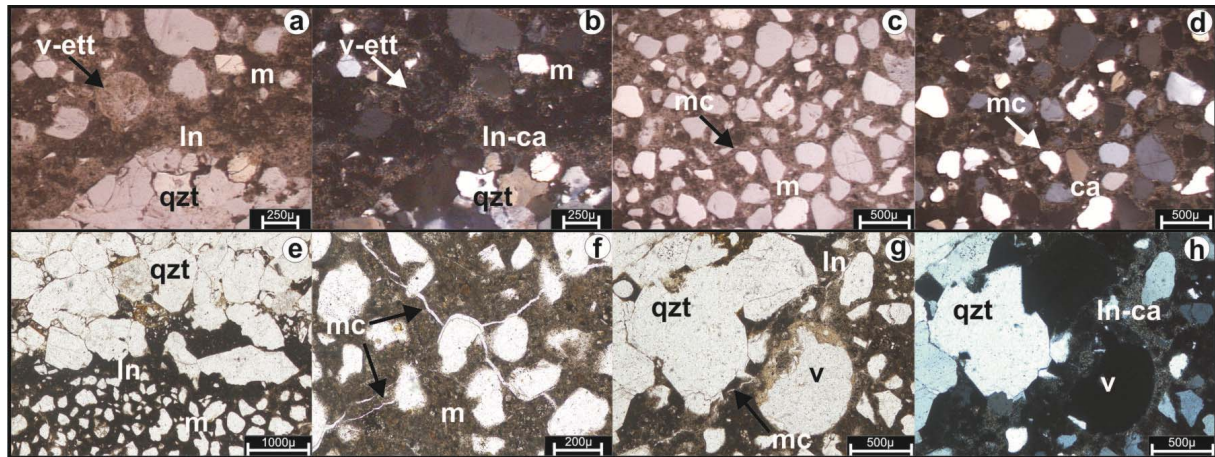


Figure 4: Polarizing microscope images of thin sections. a–d Images of base slab concrete. (a–b) Under parallel light and crossed nicols, respectively. Orthoquartzite making up the coarse aggregate (qzt); the mortar is sound and the interface is partially carbonated (In-ca). Entrained air void filled with ettringite (v-ett). (c) Under parallel light, mortar (m) where very fine microcracks (mc) have developed. (d) The same image under crossed nicols; the mortar is carbonated (ca). e–h Images of the surface slab concrete. (e) Under parallel light, area of the quartzitic aggregate (qzt)–mortar (m) interface in good condition, with no cracks. (f) Unfilled microcracks (mc) affecting the mortar (m) and some interfaces with the fine aggregate. (g) Under parallel light and (h) under crossed nicols; area of the interface with the quartzitic aggregate (qzt) that is partially carbonated (In-ca) and affected by a microcrack (mc) and an entrained air void (v) partially filled with calcite and/or portlandite. In short, the microstructure of the concretes examined does not show reaction phenomena or deterioration processes affecting the coarse or fine aggregate. The aggregate–mortar contacts are clear, with no reaction rims or cracked particles. Microcracking and carbonation in the paste are rare. The main material filling mortar voids is ettringite, which also appears on the mortar surface.

3.3 Scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS)

The reaction products were separated under a stereomicroscope for their morphological and compositional analysis by SEM–EDS.

A larger quantity of material could be obtained from the base slab concrete for the analyses. Figure 5a shows crystals of fibrous habit characteristic of primary ettringite and Fig. 5b the chemical analysis of the material by EDS, where S, Al, O and Ca attributed to ettringite were identified.

Figure 5c shows ettringite crystal growth inside an entrained air void and Fig. 5d the corresponding EDS spectrum, where the low-intensity Si peak was assigned to quartz from the aggregate.

Although the C peaks observed in both spectra are partly due to the material used to metallise the samples, the high intensity (especially in Fig. 5b) associated with the Ca peak intensity is assigned to calcite.

Besides, although the material collected from the surface slab was scarce, fibrous ettringite and well-developed calcite crystals could be identified.

3.4 X-ray diffraction (XRD)

The products collected from the base slab concrete voids were analysed by XRD. The reaction material developed inside the pores and on the mortar surface was separated under a stereomicroscope to be examined by XRD in order to identify the species present. As scarce material had developed, it was difficult to concentrate a large enough quantity for the analysis, which was also difficult due to the low crystallinity of the products related to the quartz from the fine and coarse aggregates. Figure 6 shows the XRD patterns indicating that the main reflections correspond to quartz with subordinate calcite. A very low intensity reflection peak at 9.70 Å, attributed to ettringite, was identified.

3.5 Discussion of results

The concretes from the base and surface slabs have similar petrographic characteristics. The differences found may be attributed to the different micro-environmental conditions they were exposed to. The presence of ettringite in the pores in the base slab concrete would be related to the greater flow of rainwater that would permeate through the joints and cracks on the surface slab and capillary water from the underlying layers (subgrade and granular sub-base). The surface slab exhibits greater carbonation of the cement paste, as well as pores partially filled with calcite, probably due to greater concrete exposure to rainwater and traffic gases. Mortar microcracks are rare and of small thickness. They are not typical of an internal deleterious reaction such as the ASR or external sulphate attack, as confirmed by SEM–EDS and XRD.

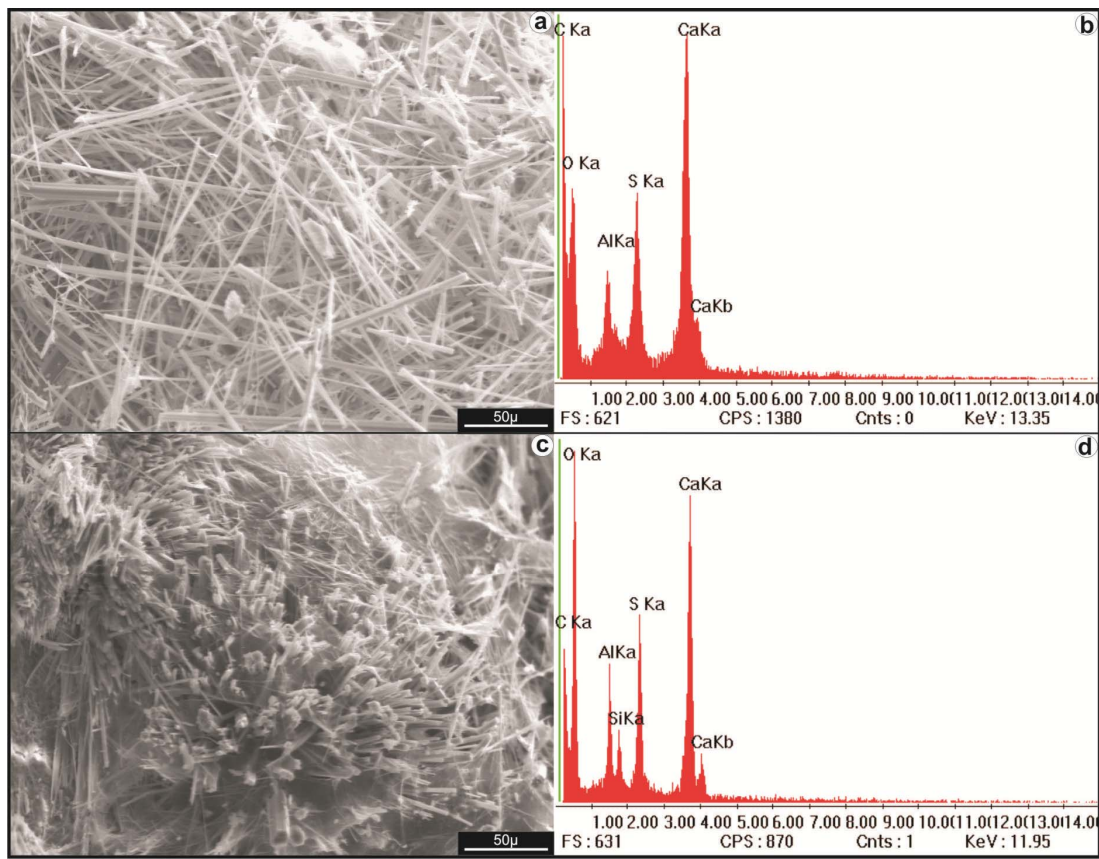


Figure 5: SEM–EDS. (a) Fibrous habit typical of primary ettringite. (b) Composition of the material shown in Fig. 5a. S, Al, O and Ca attributed to ettringite. (c) Ettringite crystal growth inside an entrained air void. (d) EDS spectrum of the material shown in Fig. 5c.

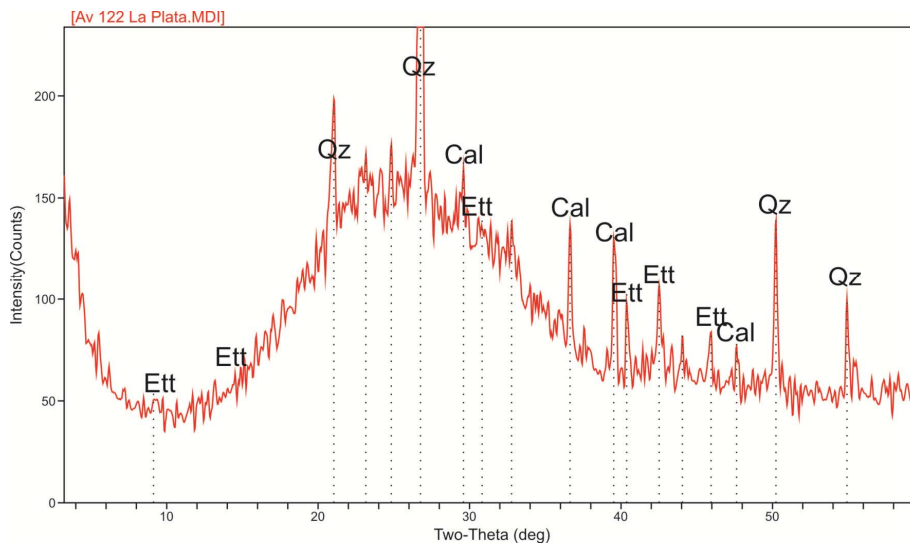


Figure 6: XRD pattern of the reaction material developed inside entrained air voids and on the mortar surface. Ett: ettringite, Qz: quartz, Cal: calcite.

4. CONCLUSIONS

- The petrographic examination by the ASTM C 856 standard method revealed a good state of conservation of both concretes, consisting of a quartzitic coarse aggregate with little or no change in its properties, as well as an interface and cohesive mortar in good condition with rare unfilled cracks.
- The materials filling entrained air voids are mostly attributed to ettringite, in some cases to calcite and portlandite, as confirmed by SEM–EDS and XRD.
- The microscopic study did not show any evidence of deleterious reaction development (e.g. ARS); however, the macroscopic characteristics of the surface slab concrete such as cracks are attributed mainly to the action of loads.

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