STUDY ON USAGE OF CHRYSOTILE FIBER IN CEMENT ROOFING SHEETS

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Executive summary

The Sri Lankan government has announced to banned Asbestos roofing sheets. And they have introduced an alternative instead to use as roofing materials similar to asbestos but made of fiber cement. This study was conducted to understand the quality difference of alternative fiber cement roofing materials introduced by the government. The study was conducted to compare the engineering properties of both different roofing materials. In this study, the quality checking and standard tastings were carried out to understand the strength durability etc. variation between tho9se two materials. In addition, the main types of roofing applications are the roofing sheets and ceiling sheets. Both have different quality aspects and standards. Therefore, both different roofing sheets were taken into consideration separately and checked the engineering properties separately.

The study was directed at the University of Moratuwa under the supervision of Prof. Asoka Perera, Prof.S.M.A Nanayakkara, and Prof.Rangika Umesh Halwatura. The study was carried on by Archt.Chameera Udawattha and Eng.Damrunwa Biblegedara. The study was conducted at the materials testing lab and the structural testing lab. In addition to strength, the chemical studies were done in the chemical lab and the material resistant to acid was done in the environmental lab. The study was conducted after following series of standards testing defined and developed by the ISO in order to confirm the quality of both types of roofing sheets. The usage and the technical aspects of both produced were compared according to the ISO standard such as ISO 8336 Fibre-cement flat sheets -- Product specification and test methods and ISO 10904 Fibre-cement corrugated sheets and fittings for roofing and cladding. Sri Lankan standards are covering both and the results were used to analyze the technical aspects of these produced to the conformity of SLS standards by using results obtained by the total study.

The study suggests that the fiber cement roofing sheets cannot replace the quality requirement for roofing sheets. Instead, the engineering properties of the fiber cement roofing sheets are lower than the crystalline asbestos roofing sheets. The study suggests that existing fiber cement roofing sheets are far below the required quality of roofing sheets. In addition to quality testing, the total life-cycle cost was studied, because the Lifecycle cost comparison will give a better idea of the use of the low-quality material as roofing materials. The results show that the fiber cement roofing cement should be replaced frequently and the total life-cycle cost is comparatively higher than crystalline asbestos roofing sheets.

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Introduction:

Usage of asbestos and its toxicology has been a well-studied topic by the researchers since early 1900s. Asbestos was introduced to industrial applications in mid-19th century and later was found out to be the main cause for elevated air pollution and lung diseases. Based on the reports produced by Lynch and Smith in 1935 and several other asbestos pollution related publications, many developed countries banned asbestos (Kurunthachalam, 2013). Though 52 countries have banned all forms of asbestos, still many countries use asbestos with more than 95% being chrysotile. No proper basis has been produced to exempt chrysotile from being banned (Ramazzini, 2010). So, this has caused controversy between the researchers on this matter. Researches on possible substitutes such as Cellulose and PVA are being done, but an ideal replacement for asbestos is not yet found. This chapter contains a detailed review on the researches undertaken on these issues.

Background Information on Chrysotile Asbestos:

According to United States Environmental Protection Agency six set of minerals belonging to two categories (Amphibole and serpentine) fall into the definition of 'asbestos'. Amosite, crocidolite, tremolite, anthophyllite and actinolite are from amphibole group whereas chrysotile is the sole member of serpentine group. Asbestos is known to have high tensile strength, low electrical conductivity, high resistant to heat and high friction coefficient. The measured tensile strength of asbestos fibre ranges between 1.1-4.4GPa which is more than the tensile strength of steel. Asbestos is insoluble in water and both types of asbestos have a high level of chemical inertia towards strong alkalis with extended periods (Virta, 2001). In addition to these Barbalace (2004) mentioned in her study that the odour and taste of the asbestos are imperceptible. So, Due to its physical and chemical properties, asbestos is a high demanded material in the world of industrial chemistry.

Amphibole and chrysotile can be differentiated by their chemical structure, size and shape. Amphibole's structure is made of double chain of tetrahedral silicate with silica on the outer side of the fibre. (Bernstein, et al., 2013) Although all five members of the amphibole family share the same structure, their chemical compositions are different. This variance in composition results due to the ability of the silicate framework to accommodate mix of different ions. The idealized chemical formulas of all five asbestiform varieties of amphibole are listed below. Within these crocidolite and amosite were the only amphiboles which were used in industrial applications (Bernstein & Hoskins, 2006).

Crocidolite	$(Na_2Fe_3^{2+}Fe_2^{3+})\ Si_8O_{22}(OH)_2$
Amosite	$(Fe^{2+},Mg)_7\ Si_8O_{22}(OH)_2$
Tremolite	$Ca_2Mg_5\ Si_8O_{22}(OH)_2$
Anthophyllite	(Mg, Fe2+)7 $Si_8O_{22}(OH)_2$
Actinolite	Ca2(Mg, Fe2+)5 $Si_8O_{22}(OH)_2$

Chrysotile has the approximate composition of $Mg_3Si_2O_5(OH)_4$ and is a sheet silicate composed with silica tetrahedral and magnesium hydroxide octahedral sheets to each layer. The former is in a pseudo hexagonal network and is joined to the latter, in which on one side, two out of every three hydroxyls are replaced by apical oxygens of the former. As these two components are different in dimension, there is a mismatch in the structure, but is compensated for, partially, in different ways by the different serpentine polymorphs (Cressey & Whittaker, 1993).

As mentioned above, the silicate sheet is smaller in dimension which causes the chrysotile fibres to curl. So, generally chrysotile has a wavy shape and normally occurs in bundle whereas the amphibole is straight and rod shaped (Borzellecca, 2004). Due to its structure, amphibole is insoluble at any pH level that might be encountered in an organism ((Speil & Leineweber, 1969). On the other hand Rozalen, et al. (2014) found out in their results that chrysotile dissolves faster in acid media and oxalate acts as a strong catalyst increasing the efficiency of magnesium release to solution at ambient temperature. The magnesium roll which is in the outer layer of the chrysotile bundle is attacked by the acid milieu inside the macrophage. This causes the sheet of chrysotile fibre to break apart and deteriorate into small pieces. Then these pieces are cleared through mucociliary and lymphatic clearance by the macrophages (Bernstein, et al., 2013). This low bio persistent ability of the chrysotile fibre is the reason behind the exemption from banning of chrysotile in contrast to amphibole. However, still researchers are debating on the hazard level of chrysotile due to the impurity.

Though there was no amosite or crocidolite fibres found in the samples collected in Chinese Chrysotile mines, a significant level of tremolite and anthipholite were found in the samples (Tossavainen, et al., 2001). Similarly a percentage of tremolite/anthipholite fibres were found in Canadian Mines (Gunter, et al., 2007) and Russian Mines (Tossavainen, et al., 2000). Also a high degree of tremolite fibres have been observed in the lung tissue samples of patients with malignant mesothelioma whereas only a small percentage of chrysotile fibres (≥5 µm in length) were found (Roggli, et al., 2002). So, it has been suspected for many years that tremolite fibres from the amphibole group which is a low level contaminant of chrysotile asbestos, could have contributed disproportionately to the incidence of mesothelioma and other exposure-related cancers (McDonald & McDonald, 1997).

So while one side support on this view, another side argues that chrysotile without tremolite can cause peritoneal mesothelioma (Egilman & Menendez, 2011). The currently available evidence in scientific literature does not prove that tremolite contamination causes the mesothelioma excesses observed in the studies of chrysotile-exposed workers. Similarly the question whether chrysotile asbestos is less potent than the amphibole forms of asbestos has not been answered (Stayner, et al., 1996).

Through a review on the epidemiological studies, Smith & Wright (1996) summarizes that according to evidence, crocidolite and chrysotile forms of asbestos have been the major causes of pleural mesothelioma in asbestos related workers. They also added that even with the consideration that crocidolite and amosite are 10 times potent than chrysotile, the extent usage of chrysotile means it would still be one of the main contributors. But, Bernstein (2014) study suggests that even though amphibole asbestos is highly pathogenic and quickly produces interstitial fibrosis with fibres translocating to the pleural cavity which initiates pathological response, chrysotile dissolves in the lungs and doesn’t produce pathological response in both short-term and sub-chronic inhalation toxicology studies in either the lung or pleural cavity.

Also Bernestein et al (2015) performed a study on rats to evaluate the pathological response in the lung due to short term exposure (6h/day for 5 days) of chrysotile, mixture of chrysotile and crocidolite. No pathological response was seen in the samples exposed to chrysotile and mix of chrysotile whereas the crocidolite had produced a rapid inflammatory response. Also the chrysotile fibres and crocidolite fibres found in the mediastinal lymph nodes were around 0 µm and 35 µm respectively.

But, the study done by Yano, et al. (2001) demonstrates that exposure to pure chrysotile asbestos may have an increased risk of lung cancer up to a level which can be comparable to the risk caused by mixed type asbestos. In addition, the results suggest that exposure to pure chrysotile can also cause mesothelioma. This study is criticized by Bernstein et al (2013) after careful review and interpretation of data, that it is not representative of chrysotile alone as there is other numerous elements which are not taken into account.

Though chrysotile dissolves in the lungs, an important point to be noted is that the fibrogenicity and carcinogenicity of asbestos fibres are also determined by other parameters such as fibre size and dimension (Boulanger, et al., 2014). Studies on chrysotile workers suggest that exposure to long and thin fibres tend to increase the risk of lung cancer (Stayner, et al., 2008; Loomis, et al., 2010).

Global Use of Asbestos:

The total world production and consumption of asbestos was extensive in the first three quarters of the 20th century. But later in the final quarter, the demand for asbestos reversed (Virta, 2001). Currently chrysotile accounts for more than 95% of the total asbestos used worldwide and crocidolite is only being used for some special purposes (Landrigan, et al., 1999).

Production of asbestos has shifted from developed countries such as the United States to the developing countries such as Brazil, India, Indonesia, Pakistan, and Korea. Similarly the consumption of asbestos is being phased out in developed countries, but consumption in Brazil is increasing at about 7%/year. What is not used domestically is exported mainly to Angola, Argentina, India, Mexico, Nigeria, Thailand, and Uruguay (Rahman, et al., 2001).

Canadian government is supporting the asbestos industry despite the suffering of the workers engaged in asbestos-related work. The export of Canadian asbestos to the developing countries is going to create another preventable occupational disease epidemic for the near future (Brophy, et al., 2007). An estimate done on the level of occupational burden on the asbestos related cancer in the Latin-American countries such as Argentina, Brazil, Columbia and Mexico revealed that the data is sufficient enough to ban the asbestos use (Pasetto, et al., 2014).

Recent EU regulation (COMMISSION REGULATION (EU) 2016/1005) on the chrysotile fibres says that the manufacture, placing on the market and use of these fibres and of articles and mixtures containing these fibres added intentionally is prohibited from 13th July 2016. However, use of diaphragms containing chrysotile in electrolysis installations or exclusively in maintenance of such diaphragms are exempted from this regulation until 1st July 2025, provided that such use is carried out in compliance with the conditions of a permit set in accordance with Directive 2010/75/EU of the European Parliament and of the Council. It is also mentioned that any user benefitting from this exemption should send a report indicating the amount of chrysotile used in diaphragms pursuant to the exemption, to the Member of state in which the relevant electrolysis installation is located by 31st January of each year.

Currently 70% of the asbestos production and nearly 50% of global asbestos consumption comes from the Asian Countries. Though most Asian countries have enforced a ban on the use of crocidolite, only Saudi Arabia, Japan and South Korea have banned chrysotile asbestos (IBAS, 2015). Singapore comes close to a full ban on asbestos whereas Vietnam is currently amending their laws and regulations to adopt a total ban of asbestos, including chrysotile. Other Asian countries, except for the campaigns done by non-governmental organizations in Malaysia and India, have not even considered banning asbestos (LaDou, 2004).

In India, asbestos fibre levels in the occupational environment of the asbestos cement manufacturing industry were found out to be lower than the Indian standards (Ansari, et al., 2010). Ramanathan & Subramaniam (2001) said that even though fibre level is low, the workers in the Indian mines are not protected and are unaware of any precaution acts. This situation eventually leads the people to more exposure to the asbestos.

Asbestos are still being used widely in Malaysia under the controlled concept, especially in buildings at rural areas, despite the fact that their use has been prohibited in schools, hospitals/clinics and government buildings in 1999 and 2005 respectively (Zen, et al., 2013). In Thailand, there is no evidence that Thai Citizens are suffering with lung diseases due to the exposure to asbestos. But, still Thailand government is concerned in controlling the use of asbestos in the industrial processes (Bovornkitti, 2011). It can be seen that Asian countries are reluctant to ban asbestos and which is due to numerous factors ranging from political and economic to the lack of understanding of asbestos and the management of asbestos-related lung diseases (Leong, et al., 2015).

Use of Asbestos in Sri Lanka

In Sri Lanka, blue asbestos was banned in 1997; however white asbestos is in use mainly as roofing sheets. Chrysotile asbestos is the second largest roofing material in Sri Lanka with 35.1% of the housing units having used it in 2012 (Statistics, 2012). In 2011 and 2012, Sri Lanka was ranked 10th in the leading countries in the Global asbestos fibre consumption with an average fibre consumption of 61,000 and 54,000 tonnes respectively. But in 2013 the consumption has reduced by more than half of the amount consumed in 2012 (IBAS, 2015).

Specific Information on Chrysotile Cement Roofing and Flat Sheets in Sri Lanka:

There are not many studies done on the processes and specifications of chrysotile cement roofing sheets in Sri Lanka. Generally AC sheets are manufactured in wet mode using 'Hatschek Process'. Initially pressure pack impermeable polythene bags of chrysotile are opened using semi-automatic machine and are mixed with cement, fly ash and water in the mixing tank. The slurry is fed into a sieve cylinder covered by mesh cloth and a thin film of stock is left as the cylinder rotates. Then the excess water is removed through vacuum box as the felt travels towards the sheet formation drum until the desired thickness is formed. Then the wet plain sheets are corrugated in a template and are stacked for initial maturity of 15-18 hours. Finally they are stripped off from the template, cured and are stored vertically for 25-28 days to reach its optimum strength (Ansari, et al., 2007). In a few words, Asbestos is manufactured by wetting the mixture of asbestos fibres and Portland cement and pressing it into a flat/corrugated sheet (Bogahawatte, 1993).

In the life cycle of AC sheet, the initial stage is the extraction/manufacturing of the input materials which are chrysotile asbestos, Portland cement, fly ash, cellulose fibres and filler (sheets that are crushed and reused in production). These raw materials are packaged using wood and plastic ties and are transported to the manufacturing plant. The sheets are manufactured using the above mentioned process and are packaged and distributed to the customers to be installed. At the end of the AC sheet's service life (final stage of life cycle), depending on the country's policy the AC sheet is disposed. In Portugal it is disposed at landfill site (Frazão, 2004).

During installation it is recommended to use manually operated machines instead of mechanically operated machines for cutting and drilling the sheets. Also the cutting and drilling should be done in an open ventilated area to keep the dust level minimum. Dust can also be reduced by using water during cutting and drilling. Also the person dealing with asbestos should wear protective mouth/nose and eye guards. Waste created during the work should be collected in impervious bags and should be buried underground (Mascons, Ramco)

Specifications for Corrugated AC Sheets:

Under Sri Lankan Standard SLS 9:2002: Part 2, asbestos cement corrugated sheets should cover the following requirements to be accepted.

- Breaking Load - ≥ 5kN/m2
- Density - ≥ 1200 kg/m3
- Water Absorption- 28% of dry mass
- Water tightness- No formation of drops
- Resistance to acidified water – 1.15 kg/m3

The standard dimensions mentioned for the corrugated sheet in the SLS 9:2002: Part 2 is given in the table below. However, tolerances on the dimensions are accepted up to the given levels as per the standard.

Standard length	mm	1750, 2400, 3050,3600
Standard Width	mm	1090
Pitch of corrugation	mm	146
Height of corrugation	mm	48
Thickness	mm	6

Though a range of lengths are mentioned in the standard, 1750mm, 2500mm, 3000mm and 3500mm long sheets are sold by the suppliers in Sri Lanka (Mascons, Rhino).

Specifications for Flat sheets:

Under Sri Lankan Standard SLS 9:2002: Part 1, asbestos flat sheets should cover the following requirements.

- Bending strength(Loading parallel to asbestos fibre)- ≥ 13MPa
- Bending strength(Loading perpendicular to asbestos fibre) - ≥ 16MPa
- Density - ≥ 1200 kg/m3
- Water Absorption- less than 28% of dry mass
- Resistance to acidified water – 1.15 kg/m3

The nominal length and width of the flat sheet as specified in SLS is shown in the following table.

Length (m)	1.2	1.8	2.4	3.0
Width (m)	1.2	1.2	1.2	1.2

Standard thicknesses of sheets are 3.5 mm, 6mm, 9mm or 12mm $\pm$5 %.

Review of Substitute and Alternative Products

The world has been doing researches for the last three decades to find a suitable replacement for asbestos and Australia was the first country to ban all forms of asbestos first in fibre cement production and adapt to natural fibres (Coutts, 2005). But still developing countries are continuously using asbestos due to the cost. The substitutes cost only a bit more than asbestos, with the cost difference not being significant, unless large tariffs are placed on the substitutes over asbestos (Frank & Joshi, 2014).

Substitutes:

Under this study substitutes are defined as the products having similar or nearly same qualities as asbestos fibre with regard to durability, noise/heat absorption, shape/size, weight and cost. In addition to long term durability, compatibility to Portland cement matrix, process ability, availability and high mechanical properties, substitute fibres also must have high toughness, high modulus and reduced elongation at rupture (Ikai, et al., 2010). The toxicity of the substitutes should also be taken into account before selecting the fibres. For the substitutes to be non-hazardous one of the key attributes is that they should have low potential to release fibres with critical fibre dimensions. Fibres with a diameter less than 3 µm, with a length greater than 5 µm and a length to diameter ratio more than 3 are defined as critical fibres (WHO, 1986) and this definition is used by most of the health related regulations. The main substitutes for the residual uses of chrysotile are p-aramid, poly vinyl alcohol (PVA) and cellulose fibres (Harrison, et al., 1999).

PVA:

PVA fibre has been used in cement applications throughout the world from 1980. Though there are different type of PVA fibres in the market, the typical parameters such as tensile strength, Young's modulus, fibre elongation and density of PVA reinforcing fibres are in the range of 880–1600 MPa, 25–40 GPa, 6–10% and 1.30 g/cm3 respectively. PVA fibre has high tenacity and modulus of elasticity when compared to the other organic fibres (Horikoshi, et al., 2006).

The presence of the hydroxyl groups in PVA fibre provide electrostatic attractive and hydrogen bonding interactions on the molecular scale. These interactions enable remarkable changes in the surface bond strength between the aggregate and the matrix and also between the fibre reinforcement, the matrix and its aggregates (Toutanji, et al., 2010).

When comes to durability, the study done by Akers,et al(1989) suggests that PVA fibres which contribute to the reinforcement of the cement matrix are durable over a period of at least 7 years, and it can be believed that these fibres will continue to be durable for extended periods.

As the PVA fibres have a lower density (- 1.3) when compared to mineral fibres, the critical diameter will be 7 µm versus 3 µm for mineral fibres. However, the fibres are mostly within the range of 10-16 µm. Also there is evidence that they do not fibrillate (split lengthwise). So, PVA fibres are well above the critical dimension and are not inhalable (Harrison, et al., 1999).

In the fibre cement industry, PVA fibres are normally injected into the water cement mix without any mechanical alteration such as cutting. There is a possibility for mechanical alteration or damage of PVA fibres when fibre-cement end-products are machined. However, when the fibre cement corrugated sheets were sawed, the organic fibre level remained very low which suggests that PVA has low ability to release particles with fibrous dimensions (Raeve, et al., 2001).

Cellulose:

Cellulose fibres can be found as natural (native) or man-made (regenerated) and the crystal structures of these are known as cellulose I and II respectively. In the cellulose I form there are two intramolecular hydrogen bonds between the successive anhydroglucose units O(2')..0(6) and O(3) ... 0(5') and in the cellulose II form only a bihrcated intramolecular hydrogen bond O(3) ... 0(5'),0(6') is found parallel to the ether bridge. This two different conformations of the hydroxyrnethyl group that cause the difference in intramolecular hydrogen bonding affect the ultimate tensile properties of the fibres. The modulus of the cellulose I chain and cellulose II are determined as 140 GPa and 90 GPa respectively (Northolt, et al., 2001).

Though cellulose is not uniformly crystalline, crystallites are extensively distributed all over the material. Micro fibril which is thread shaped arises from the linear association of these components, and it forms the basic structural unit of the plant cell wall. These micro fibrils contain 2–30,000 cellulose molecules in cross-section and are around 10–30 nm wide, less than this in width, and indefinitely long (Eichhorn, et al., 2001).

Cellulose fibres exhibit improved toughness, ductility, flexural capacity and crack resistance compared with non-fibre-reinforced cement-based materials. The advantage of fibre reinforcement is that they bridge the matrix cracks and transfer the loads after cracking has started. This post cracking toughness allows more intensive use of cellulose in building. Cellulosic fibres also provide adequate strength, stiffness and bonding capacity to cement based matrices for substantial enhancement of their flexural strength, toughness and impact resistance (Ardanuy, et al., 2015). In addition to the relatively high strength and toughness, Cellulose fibre is readily available and provides desired longevity, fire resistance and life cycle economy (Soroushian, et al., 2012).

Cellulose fibre is known to be an eco-friendly thermal insulation material which offers good thermal properties and has a low embodied energy. However due to lack of expertise in its application and properties, cellulose is not widely used in insulation compared to more traditional insulation materials (Hurtado, et al., 2016). According to the thermal performance, the roofing sheets reinforced with vegetable fibre are said to be acceptable as substitutes for asbestos-cement sheets (Roma, et al., 2008). In a climate similar to Southern USA, the cellulose reinforced fibre composite has a good and satisfactory performance for periods more than 18 years, if installed in a correct manner and maintained subsequently. However, cellulose has less need for maintenance than other materials because of its high inherent durability (Cooke, 2000).

Cellulose has been in use in the paper industry for many years, but only little evidence is recorded for disease in relatively high exposure. But this can be due to the limited epidemiological studies undertaken in the past. Although some surveys have shown that cellulose has the potential to produce respirable fibres, the extent of fibrillation is not established (Harrison, et al., 1999). Similarly the study undertaken by Cullen et al (2002) to determine the toxicity of the cellulose shows that respirable cellulose fibre was less toxic in vitro than the mineral fibres crocidolite. However, in the in vivo tests, high exposure to cellulose fibres produces harmful effects including tumours. Only few of the samples studied contained mesothelioma whereas the others had sarcomas which are not normally observed with mineral fibres. So the ability of cellulose to cause pulmonary carcinomas following inhalation is still not clear and further studies on long term inhalation is required.

P-aramid:

P-aramid fibres have been used as a substitute for chrysotile asbestos, mainly in brake linings and gaskets (Warheit, et al., 1997). Aramid fibres were the first organic fibres with high tensile strength and modulus to be used as reinforcement in composites. They have better mechanical properties than synthetic fibres, steel and glass and also they are able to maintain these properties and high temperature due to their high heat resistant ability. Densities of aramid fibre range from 1.35-1.45g/cm^3 according to its properties (Jassal & Ghosh, 2002).

Studies done on rats to compare the pulmonary effects made by chrysotile asbestos and para-aramid fibres showed that inhaled para-aramid fibres were bio degradable in the rats' lungs whereas the long chrysotile asbestos fibres retained (Warheit, et al., 1996, 1997).

Researches are going on to find more substitute fibres for asbestos apart from the above mentioned three fibres(PVA,Cellulose and p-aramid). Some of those are ;

Alternatives:

Under this study alternatives are defined as the products which provide the same purpose of asbestos, mainly roofing. A roofing material is considered to be good if it is adequate to withstand the loads within its life span. This depends on the material properties such as tensile strength, density and material composition (Obam & Taku, 2015). Other than asbestos, clay tiles, concrete tiles, Zn/Al sheet and Reinforced Concrete deck are currently used in the Sri Lankan Building Industry (Perera & Fernando, 2002).

Clay Tiles:

Clay tiles are known to be the most visually attractive and distinctive traditional roofing material due to their availability in various shapes, textures, colours, profiles and patterns. In early days clay tiles were made by hand and later by machine extrusion of natural clay, glazed with colour and fired in high temperature kilns (Costa & Mauroof, 2005).

Clay roofing tiles are widely used as exterior building components and their durability which is the ability to withstand adverse climatic conditions is one of the most key requirements to be considered in the structural design of modern buildings. The service time period of the clay based components are heavily reduced due to the frost action and salt crystallisation .During the temperature drop below 0^{o}C, the water in the clay tiles freeze and the density difference between the ice and water creates an internal pressure. This leads to micro cracks in the clay tiles (Raimondo, et al., 2009).

Perera & Fernando (2002) in their comparison between roofing materials concluded that tiles have low water tightness due to their high water absorption rate and improper interlocking in side and ends. They also added due to the high probability of getting damaged, clay tiles are less durable when compared to other materials. In contrast to this, Costa & Mauroof(2005) said that clay tiles are preferred due to their durability and they generally have life expectancy for about 100 years.

By nature, clay is a not a good conductor of heat, so using clay tiles will not only save money from the energy cost but also will reduce the internal temperature. This makes it an ideal material for the roof (Costa & Mauroof, 2005).A study was done recently by Srimanna & Attalage (2016) to identify the thermal performance of the roofing materials which are widely used in Sri Lanka. The results showed that out of clay tile, asbestos and steel roofing; clay tile has the best thermal performance, whereas steel roofing has the worst. Compared to clay tile roofing, asbestos roofing and steel roofing can have a higher ceiling temperature by 4 ◦C, 6 ◦C respectively.

Based on the study done by Kuruppuarachchia, et al (2007), it can be concluded that clay based roof tile manufacturing is more environmentally friendly in both traditional and modern methods than cement and asbestos fibre roofing sheets in impact categories such as respirable inorganics, climate change, eco toxicity, acidification and fossil fuels.

Metal Corrugated Sheets:

In the building industry, with the continuous search for better alternative roofing materials, metal roofing is gaining lead in the last decade, driven by long-term economic benefits and sustainability. Some other reasons for the preference of metal roof over conventional asphalt based roofing in residential and commercial buildings are longevity, good looks, availability in vivid colours and patterns, wind and fire resistance, better leak protection, lower maintenance costs and recyclability . (Anugula, et al., 2012).

In the construction industry, to promote resource conservation and reduce maintenance work, construction materials should be highly durable. In the case of metal, mainly organic composite coated steel sheets, corrosion is the main concern. So, these sheets should have basic properties such as corrosion resistance and formability (the property that suppresses the peeling and scoring of metal coatings during roll forming). In addition to these properties, pre-painted steel sheets should have an excellent surface appearance which is free from cracks and other damage even after forming. As the Zn coated steel sheets have a limit in the increase of corrosion resistance, the usage of Zn-Al alloy coated steel sheets which is more corrosion resistant is increasing. (Yamashita, et al., 2002).

Generally, metal roofing sheets (zinc, aluminium, galvanized sheets etc.) expand due to air temperature change and the heat from the sun. Aluminium, one of the widely used metals for roofing sheets, is soft, malleable, ductile, and light weighted with a dull-silvery colour which is caused by the Aluminium oxide that forms quickly due to the exposure to air. Aluminium oxide has a higher melting point than pure aluminium. Due to this protective oxide layer, aluminium sheet is durable and has excellent corrosion resistance. Aluminium has about one-third of the density of steel or copper. The tensile strength of aluminium in its pure state and alloy state is about 49MPa and 400 MPa respectively (Obam & Taku, 2015).

PVC Sheets:

PVC roofing systems were introduced to the market in the late 1950s and early 1960s. The initial system had unreinforced PVC sheets which were held in place by ballast and were attached at the perimeters and field flashing locations. In late 1970s, the PVC roofing system gained demand and in early 1980s, marketing of reinforced PVC sheets that were also placed by ballast started. Later in the 1980s it was found out that aged PVC sheets fail when they experience a high impact load during hail storms (Koontz, 1997).

A study done to evaluate the life time of PVC roofing membranes showed that roofing systems which had an average life time of 20 years were performing well without any leakages. As the roofs examined were the oldest, it was not possible to predict their remaining life time. However, by considering the age and the condition of the roofs analysed, it was suggested that reinforced PVC roof membrane system could perform in excess of 20 to 30 years in various climates throughout Europe and North America if properly installed and maintained (Beer, et al., 2005).

PVC in similar to asbestos ceiling sheet has low density, low thermal conductivity and high thermal resistivity which was favourable when compared to other thermal insulators. PVC ceiling with its physical appearance, strength, chemical resistance, fire resistance, maintenance-free and freedom from toxicity, odour, and taste may be a better material for thermal design application (Onyeaju, et al., 2012).

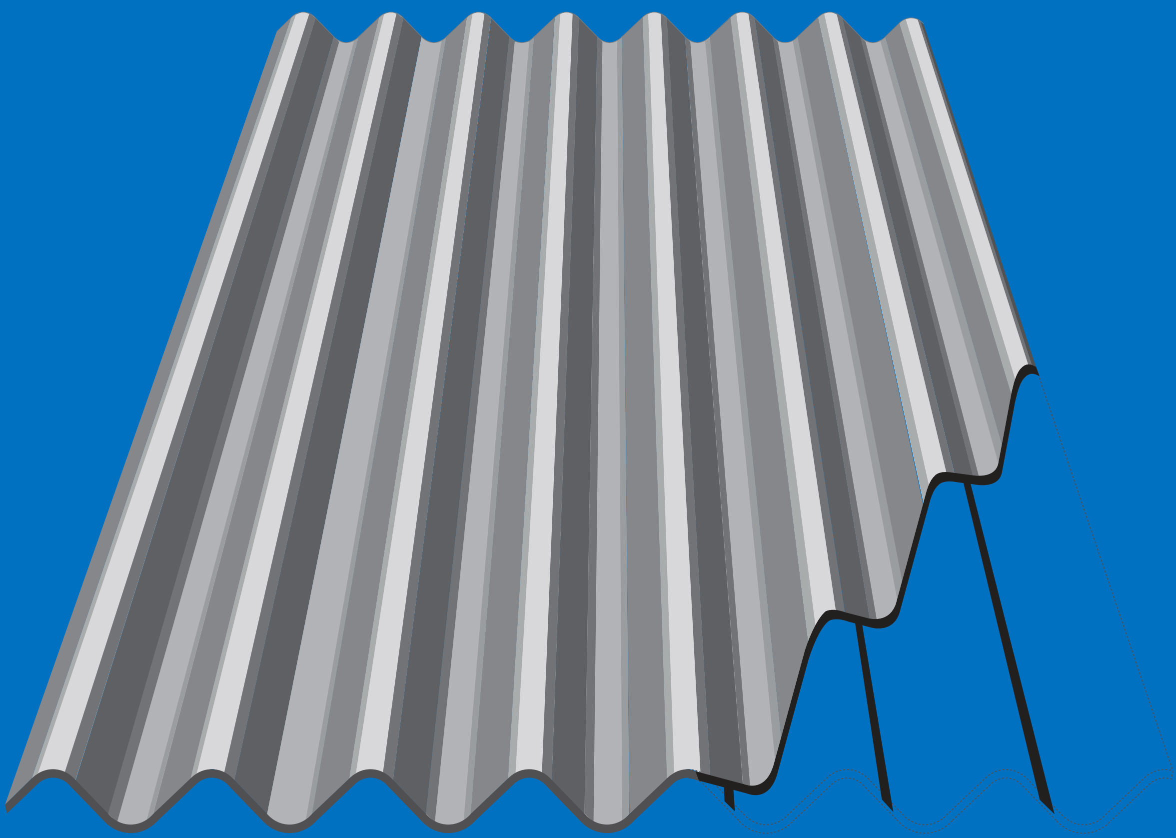
The initial method to evaluate the test results of the asbestos sheets are the test with the main sheets and confirm the quality of asbestos sheets and come up with a proper standard for the asbestos sheets.

And following standard tests were being carried out in order to confirm the standard of existing crystallite asbestos sheets and fibre cement roofing sheet products.

Criteria of Conformity

1. When tested, only one defective sheet is acceptable in the sample.
2. The test results should conform their specific standard conditions listed below in the table

	SLS:9:Part 1:2001	SLS:9:Part 2:2001	ISO 8336:2009	ISO 10904:2011
	Asbestos Flat Sheets	*Asbestos Corrugated Sheets*	*Non- Asbestos Fibre Cement Flat Sheets*	*Non-Asbestos Fibre Cement Corrugated Sheets*
Bending Strength (Loading Parallel to Asbestos Fibres of the sheet)	≥ 13MPa		Category C; But depending on class varies; Assuming Class 4 ≥ 16 MPa	Varies according to category and class; Check Table 4 of the standard
Bending Strength (Loading perpendicular to Asbestos fibres of the sheet)	≥ 16MPa			
Breaking Load		≥ 5kN/m		Varies according to category and class; Check Table 3 of the standard
Density	≥ 1200 kg/m^3	≥ 1200 kg/m^3	≥ Manufacturer's specification	≥ Manufacturer's specification
Water Absorption	≤ 28% of dry mass	≤ 28% of dry mass	-	-
Water Tightness/water permeability	-	Trace of moisture may appear; But no droplets	Trace of moisture may appear; But no droplets	Trace of moisture may appear; But no droplets
Resistance to Acidified Water	≤ 1.15 kg/m^2	≤ 1.15 kg/m^2	-	-
Moisture Movement			≤ 0.07%	-
Freeze-Thaw performance				≥ 0.7
Heat-Rain Performance				No visible cracks, delamination or other defects should be present to a degree that would affect performance
Warm Water performance			≥ 0.8	≥ 0.7
Soak-Dry Performance			≥ 0.75	≥ 0.7
Resistance to mould growth			≤ 1	
Resistance to nail head pull through			≥ 400N	



Tested standards

1. SLS Standards
2. ISO 8336:2009
3. ISO 10904:2011

SLS Standards

Lists of tests need to be done

1) Dimension Measurement
    a) **Corrugated Sheets**
    b) **Flat Sheets**
2) Testing of Bending Strength
    a) **(Flat sheet)**
    b) **Corrugated Sheets**
3) Testing for Density
    a) **Corrugated Sheets**
    b) **Flat Sheets**
4) Testing for water absorption
    a) **Corrugated Sheets**
    b) **Flat Sheets**
5) Testing of Water tightness
    i) **Corrugated Sheets**
6) Testing for Resistance to Acidified Water
    a) Corrugated Sheets
        i) **Acetic acid 5% (m/m) solution**
        ii) **Sodium Hydroxide; 0.5M standard volumetric solution**
        iii) **Thymol blue solution (dissolve 0.04g of Thymol blue in 100 ml of 95 % (v/v) ethanol)**
    b) Flat Sheets
        i) **Acetic acid 5% (m/m) solution**
        ii) **Sodium Hydroxide; 0.5M standard volumetric solution**
        iii) **Thymol blue solution (dissolve 0.04g of Thymol blue in 100 ml of 95 % (v/v) ethanol)**

Dimensional measurement and geometrical testing procedure

General

This annex gives the details of the measuring apparatus and measuring procedure which are to be used for the determination of compliance with the requirements of this International Standard.

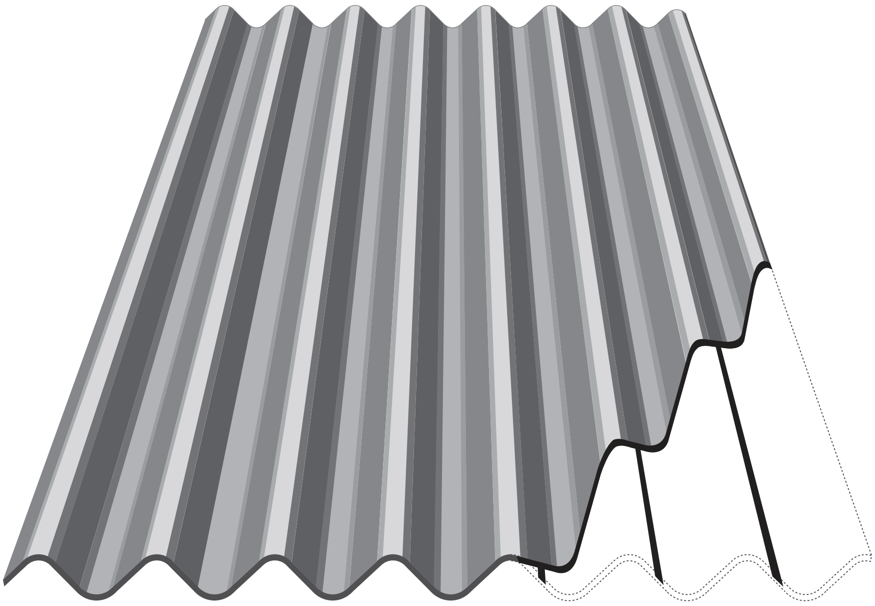


Figure 1: Corrugated Sheets dimensions

Principle

Sample sheets, selected from batches of sheets, are measured to determine their compliance with the length, width and thickness requirements of this International Standard.

Apparatus

The apparatus shall include the following items.

- **Inspection surface**, smooth, flat, rigid, of standard quality, having dimensions appropriate to the size of the sheets being measured.
- Two metal rules shall be fixed at right angles along adjacent edges of the inspection surface. The straightness of each metal rule shall be at least 0,3 mm/m and the right angle shall be accurate to at least 0,1 % (less than 1 mm deviation from normal per metre of length) or 0,001 rad.
- Alternatively a portable square of at least 1 000 mm in each direction shall be used. The same requirements for straightness and angularity apply.

Rules, short, metal, capable of being read to an accuracy of 0,5 mm.

Measuring tape, metal, of sufficient length to measure the length of a sheet to an accuracy of 1 mm.

Dial gauge, reading to at least 0,1 mm, with flat parallel metal jaws between 10 mm and 15 mm in diameter.

Measuring procedure

Measurement of length and width

GENERAL

Avoid taking the measurement over a local deformation which could be considered as a visual defect. Smooth any rough areas.

Take each dimensional reading to the nearest 1 mm.

Measure each dimension three times on each sheet, i.e. one in the middle and one at about 50 mm from either end.

Measurement of Sheets

For large-sized sheets make three thickness measurements, with a dial gauge, along one side of the sheet taking each reading to an accuracy of 0, 1 mm, as indicated in Figure 3. Report the individual results and calculate the arithmetic mean and difference between extreme values.

For small-sized sheets, make two measurements with a dial gauge on each sheet, approximately 20 mm from the edge in the middle of two adjacent sides.

Report the individual results and calculate the arithmetic mean and difference between extreme values.

Dimensions in millimetres

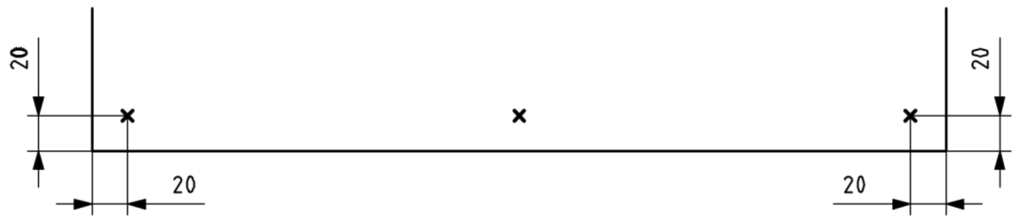


Figure 2: ***Measurement of thickness on large-sized non-textured sheets***

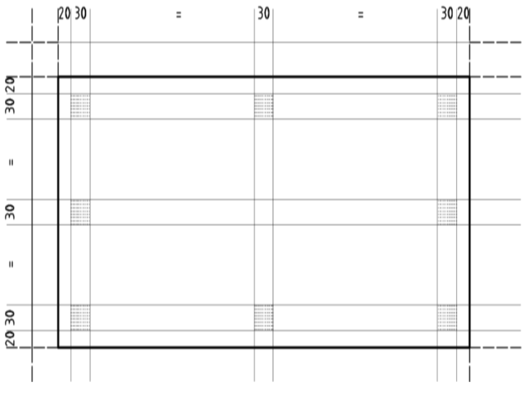


Figure 3: ***Measurement of thickness of large textured sheets***

Measurement of edge straightness

For large-sized sheets measure on all four edges the greatest distance between the edge of the sheet and a string or wire stretched from one corner to the adjacent corner with a steel rule.

Record the measured value.

TEST RESULTS: RECORD THE MEASURED VALUE

MEASUREMENT OF LENGTH AND WIDTH OF ASBESTOS CORRUGATED SHEETS

Dimensions		
1.0	Minimum Width	109.5cm
2.0	Maximum Width	109.5cm
3.0	Minimum Length	249.5cm
4.0	Maximum Length	249.7cm
5.0	Average Width	109.5cm
6.0	Average Length	249.6cm

MEASUREMENT OF LENGTH AND WIDTH OF CEMENT FIBER CORRUGATED SHEETS

Dimensions		
1.0	Minimum Width	94.0cm
2.0	Maximum Width	94.0cm
3.0	Minimum Length	179.0cm
4.0	Maximum Length	179.1cm
5.0	Average Width	94.0cm
6.0	Average Length	134.6cm

MEASUREMENT OF LENGTH AND WIDTH OF ASBESTOS FLAT SHEETS

Dimensions		
1.0	Minimum Length/Width	122cm
2.0	Maximum Length/Width	122cm
3.0	Average Length/Width	122cm

MEASUREMENT OF LENGTH AND WIDTH OF CEMENT FIBER FLAT SHEETS

Dimensions		
1.0	Minimum Length/Width	122cm
2.0	Maximum Length/Width	122cm
3.0	Average Length/Width	122cm

MEASUREMENT OF THICKNESS OF ASBESTOS CORRUGATED SHEETS

Thickness		
1.0	Minimum Thickness	6.2mm
2.0	Maximum Thickness	6.3mm
3.0	Average Thickness	6.25mm

MEASUREMENT OF THICKNESS OF CEMENT FIBER CORRUGATED SHEETS

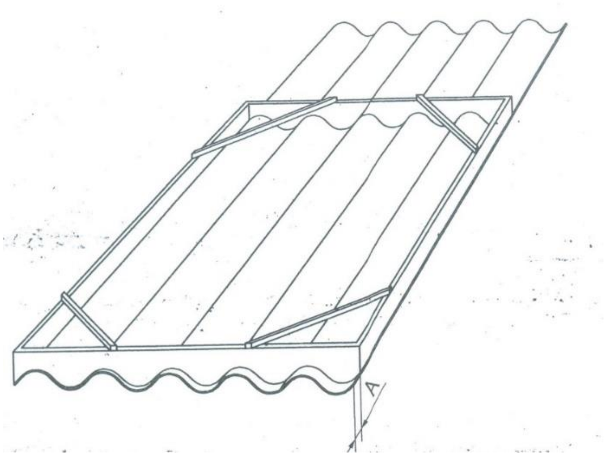
Thickness		
1.0	Minimum Thickness	2.9 mm
2.0	Maximum Thickness	3.96 mm
3.0	Average Thickness	3.14mm

Measurement of sheet square ness

Place two adjacent corners of the sheet in succession between the arms of the square keeping one edge against the full length of the large arm and the other in contact with the small arm at least one point.

In this position measure to the nearest 0,5 mm the greatest distance of the sheet edge from the small arm of the square. Record the measured value.

TEST RESULTS FOR OUT OF SQUARENESS



CRYSTALLITE ASBESTOS CORRUGATED SHEETS

	Sample 1	Sample 2	Sample 3	Average
A	11.1	11.25	10.98	11.11
B	8.74	8.56	8.93	8.743333

FIBER CEMENT CORRUGATED SHEETS

	Sample 1	Sample 2	Sample 3	Average
A	17.92	16.17	18.36	17.48333
B	21.1	17.46	16.53	18.36333

Testing of Bending Strength

General

This annex gives a method for determining the modulus of rupture for fiber-cement sheets.

Principle

A specimen is cut from a sample sheet and subjected to a flexural bending load until failure occurs, the failure load and specimen thickness are recorded. This test is repeated on the specimen with the bending mode at right angles to the initial test. The average modulus of rupture for the material is calculated from the test results.

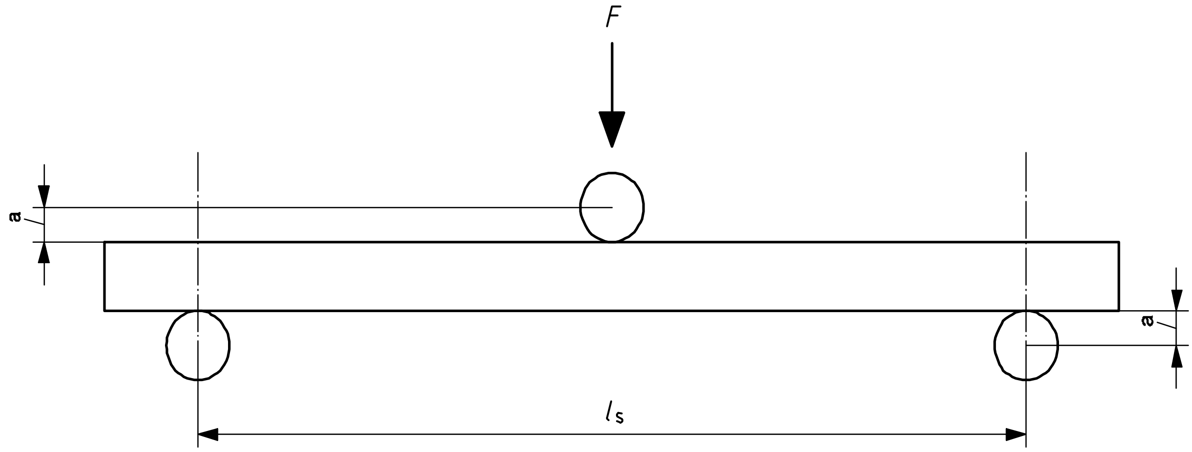
Bending testing machine, which shall apply a load at a constant rate of deflection with an error of accuracy and an error of repeatability of 3 % comprising: two parallel horizontal supports, one fixed and the second free to move to permit alignment with the specimen. The upper face of each support shall be rounded and shall have a radius between 3 mm and 25 mm (see Figure D.1).

A loading bar having the same edge radius as the supports, located parallel to and equidistant from the supports. The loading bar is attached to the loading mechanism through a flexible connection.

The lengths of the supports and loading bar shall be greater than the width of the test specimen.

Micrometer, reading to an accuracy of at least 0,05 mm, with flat parallel metal jaws between 10 mm and 15 mm in diameter.

Dimensions in millimeters



[a] 3 mm to 25 mm.

*Figure 4: **Bending test configuration***

Specimen preparation

Prepare specimens to conform with the dimensional requirements of the referring standard (see 7.3.1) and condition samples prior to testing as appropriate for the sheet category (see Table 11).

Test procedure

a) Arrange the supports to be at the appropriate spacing for the specimen.

NOTE this is normally 200 mm between bar centres, but can be altered according to the specimen characteristics (see Figure 4).

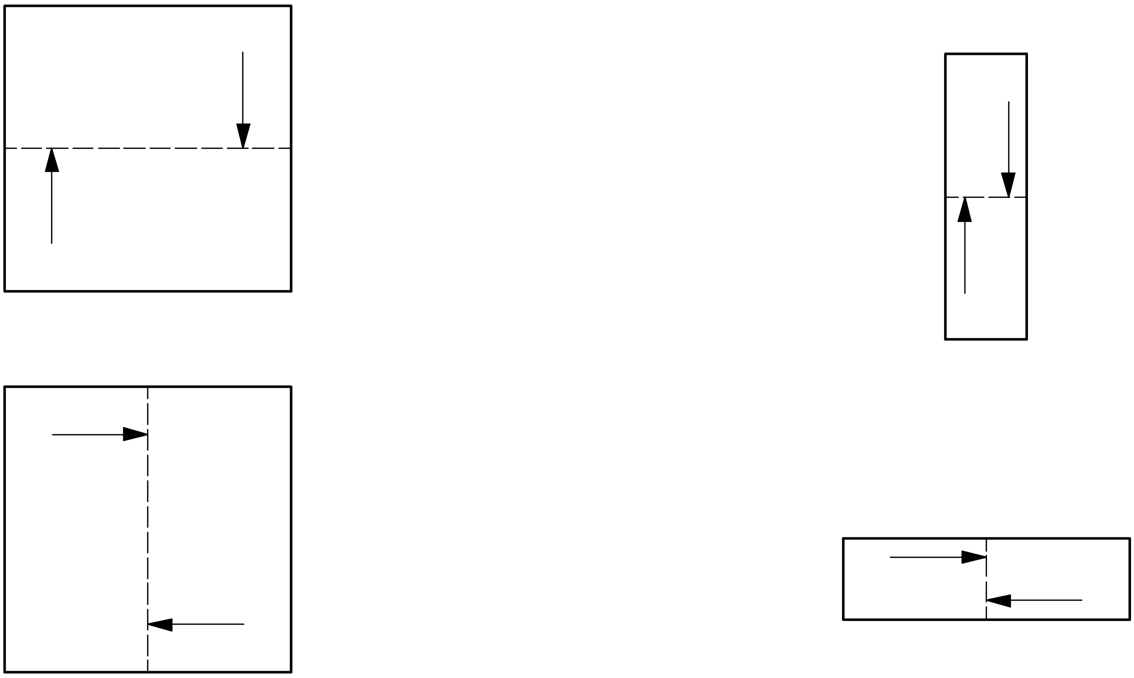
b) Measure the thickness of the sheet along the imaginary line of breakage (see Figure D.2). Measure smooth sheets at two points. For textured sheets, measure the thickness of the sheet by calculating the water displacement. Alternative methods for determination of average thickness of textured product may be used provided that they can be proven, on average, to yield a thickness measurement within plus or minus 2% of that determined from the volume measurement by water displacement.

c) Arrange the specimen with the under face against the supports and the loading bar on the upper face equidistant between and parallel with the supports.

d) Load the specimen such that the breakage occurs within 10 s and 30 s. A constant rate of deflection is preferred; if this cannot be achieved a constant rate of loading is acceptable. Record load at break.

e) For square specimens, re-assemble the broken pieces and submit the specimen to a second bending test with the line of load application at right angles to that of the first test. Record load at break.

NOTE where rectangular specimens are being used, the strengths in two directions are obtained by testing each of the appropriate specimens (see Figure D.2).



a) Square specimens b) Rectangular specimens

Figure 5 : testing breaking load of different size samples

Calculation of modulus of rupture value

The MOR, in mega pascals, for each breaking load direction is given by Equation (D.1):

$$\text{MOR} \quad \frac{3Fl_s}{2be^2}$$

Equation 1

where

F is the breaking load, in newton;
l_s is the span between the centre-lines of the supports, in millimetres;
b is the width of the test piece, in millimetres;
e is the thickness, in millimetres.

The MOR, in megapascals, for each breaking load direction is given by Equation (D.1):

for non-textured sheets, it is the arithmetic mean of two measurements for each breaking load direction, for face textured sheets, it is calculated from the volume measured by water displacement.

The MOR of the sheet(s) shall be the arithmetic mean of the five (ten) values (two values in each direction).

For initial type tests, to determine product class where production variance is unknown, an estimate of the mean MOR at the 95 % confidence level shall be determined. This shall be done by taking one square sample or two rectangular samples from a minimum of ten individual sheets, and carrying out the following procedure:

a) For each sheet calculate MOR_i as the average of MOR along and MOR across for the i^{th} sheet;

b) Calculate the mean, R_i, and the standard deviation, s, of the combined average MOR_i values;

c) Calculate the mean, R_{cl}, of the MOR_i values at the 95 % confidence level using Equation (D.2):

d) Determine the product class by comparing the R_{cl} value with the category and minimum class requirement in Table 7 (R_{cl} W Table 7 value).

TEST RESULTS :RECORDED BENDING STRENGTH FLAT SHEETS /

Modulus of rupture (bending strength) of Crystallite Flat Sheets

	Breaking Load	LS	B	E	MOR
Sample 1A	447.1N	200.0mm	250.0mm	4.9mm	22.62
Sample 1B	298.8N	200.0mm	250.0mm	4.6mm	16.87
Sample 2A	349.7N	200.0mm	250.0mm	5.3mm	14.94
Sample 2B	654.0N	200.0mm	250.0mm	5.0mm	31.90
Sample 3A	224.4N	200.0mm	250.0mm	4.1mm	15.94
Sample 3B	350.6N	200.0mm	250.0mm	3.7mm	30.40
Sample 4A	229.2N	200.0mm	250.0mm	4.3mm	14.88
Sample 4B	428.0N	200.0mm	250.0mm	4.3mm	27.78
Sample 5A	236.7N	200.0mm	250.0mm	4.6mm	13.54
Sample 5B	407.9N	200.0mm	250.0mm	4.8mm	21.25
Sample 6A	197.8N	200.0mm	250.0mm	4.0mm	14.69
Sample 6B	352.9N	200.0mm	250.0mm	4.4mm	21.48
Sample 7A	240.2N	200.0mm	250.0mm	4.7mm	13.11
Sample 7B	376.9N	200.0mm	250.0mm	4.8mm	19.47
Sample 8A	217.6N	200.0mm	250.0mm	4.5mm	13.07
Sample 8B	437.1N	200.0mm	250.0mm	4.6mm	24.90

Final results of Breaking load

Strong side Average	**431.8125**	**200**	**250**	**4.5625mm**	**24.975**
Weak side Average	**249.3**	**200**	**250**	**4.5125**	**14.63**

Modulus of rupture (bending strength) of Cement Fiber Flat Sheets

	Breaking Load	LS	B	E	MOR
Sample 1A	117.5N	200.0mm	250.0mm	3.1mm	14.76
Sample 1B	75.8N	200.0mm	250.0mm	3.12	9.35
Sample 2A	121.1N	200.0mm	250.0mm	3.2mm	14.55
Sample 2B	71.0N	200.0mm	250.0mm	3.12	8.76
Sample 3A	122.3N	200.0mm	250.0mm	3.2mm	14.70
Sample 3B	76.8N	200.0mm	250.0mm	3.12	9.47
Sample 4A	122.2N	200.0mm	250.0mm	3.2mm	14.50
Sample 4B	74.2N	200.0mm	250.0mm	3.18	8.80
Sample 5A	120.3N	200.0mm	250.0mm	3.12	14.83
Sample 5B	70.7N	200.0mm	250.0mm	3.29	7.87
Sample 6A	119.6N	200.0mm	250.0mm	3.19	14.10
Sample 6B	70.7N	200.0mm	250.0mm	3.13	8.66
Sample 7A	119.7N	200.0mm	250.0mm	3.04	15.54
Sample 7B	75.6N	200.0mm	250.0mm	3.08	9.57
Sample 8A	122.6N	200.0mm	250.0mm	3.19	14.46
Sample 8B	72.6N	200.0mm	250.0mm	3.18	8.62

Final results of Breaking load

Strong side Average	**120.7N**	**200.0mm**	**250.0mm**	**3.1mm**	**14.68**
Weak side Average	**73.4N**	**200.0mm**	**250.0mm**	**3.2mm**	**8.89**

TEST RESULTS: RECORDED BENDING STRENGTH CORRUGATED SHEET THREE PITCHES SAMPLE

Modulus of rupture (bending strength) of Crystallite Corrugated Sheets

	Breaking Load	LS	B	E	MOR
Sample 1	508N	290mm	400mm	4.9mm	22.62
Sample 2	396N	290mm	400mm	4.6mm	16.87
Sample 3	424N	290mm	400mm	5.3mm	14.94
Sample 4	424N	290mm	400mm	5.0mm	31.90
Sample 5	368N	290mm	400mm	4.1mm	15.94
Sample 6	536N	290mm	400mm	3.7mm	30.40
Sample 7	536N	290mm	400mm	4.3mm	14.88
Sample 8	564N	290mm	400mm	4.3mm	27.78
Sample 9	620N	290mm	400mm	4.6mm	13.54
Sample 10	620N	290mm	400mm	4.8mm	21.25

Testing for determination of the apparent density

General

This annex gives the test method for determination of the apparent density (see 3.4) of fibre-cement sheets. This is the average density of the material and its pores.

Principle

The volume of a saturated specimen is determined by immersion in water. The specimen's oven dry weight is then measured. The apparent density is determined by calculation from the measured values.

Apparatus

Oven, ventilated, capable of achieving a temperature of (100 5) °C with a full load of specimens.

Balance, accurate to within 0,1 % of the specimen mass, equipped to determine both the immersed mass and the non-immersed mass of the specimen.

Test procedure

a) Immerse specimen in water. Specimens having a thickness u 20 mm shall be immersed for at least 24 h.

b) Specimens having a thickness 20 mm shall be immersed for at least 48 h.

c) Take saturated specimen, remove excess water from surfaces and then determine the volume of the water displaced, V, by the saturated specimen when placed into a water bath. Record this value.

d) Remove specimen from water bath and place it into a ventilated oven which is maintained at a temperature of (100 5) °C until constant mass, m, is reached. (i.e. mass gain in any 24 h period does not exceed 0,1 % of specimen weight). Record this value.

Calculation of apparent density

The apparent density, d, in grams per cubic centimeter, is given by Equation (E.1):

$$d \quad \frac{m}{V} \qquad \text{(E.1)}$$

where m is the mass of the specimen

after drying;

V is the volume of the specimen, in cubic centimeters.

Testing for Mould Growth

General

Three Specimens with a size of 50mm x 50mm will be cut from the sample sheet. A spore suspension will be prepared with accordance to ASTM G21. Initially nutrient-salts agar will be poured into suitable sterile dishes to create a solidified agar layer with 3-6mm depth. After the agar is solidified the specimens will be placed on the agar surface and the whole surface including the test specimen surface will be inoculated with the spore suspension by spraying from a sterilized atomizer with 110kPa air pressure. The test specimens will be covered and will be incubated at 28-30^{o}C and not less than 85% of humidity for a minimum of 21 days. The growth will be recorded each day.

Principle

If the test is done for visible effects only, then the three specimens will be removed from the incubator and the mould growth will be observed and will be rated according to the following:

Observed Growth Specimen	Rating
None	0
Traces of growth (Less than 10%)	1
Light Growth (10%-30%)	2
Medium Growth (30%-60%)	3
Heavy Growth(60% to complete coverage)	4

Apparatus

Mould growth testing equipment and mould growing medium made of using required culture.

Test procedure

As physical changes might occur without considerable visible effects, the test specimens will be washed, immersed in aqueous solution of mercuric chloride for 5 min, rinsed in tap water, air dried overnight in room temperature and reconditioned at the laboratory standard conditions mentioned in ASTM D618 and will be tested according to the respected methods mentioned in the Appendix of ASTM G21 for effects on physical, optical or electrical properties.

TEST RESULTS APPARENT DENSITY

Crystallite sheets

Asbestos	Mould Growth Rate	Required standard	Test Summery	
Sample 1	5%	10%	Pass	Traces of growth (Less than 10%)
Sample 2	3%	10%	Pass	Traces of growth (Less than 10%)
Sample 3	2%	10%	Pass	Traces of growth (Less than 10%)
Average			Pass	Traces of growth (Less than 10%)

Cement fibre sheet material

Fiber Cement	Mould Growth Rate	Required standard	Test Summery	
Sample 1	45%	10%	Fail	Medium Growth (30%-60%)
Sample 2	68%	10%	Fail	Medium Growth (30%-60%)
Sample 3	80%	10%	Fail	Heavy Growth(60% to complete coverage)
Average			Fail	Medium Growth (30%-60%)

TESTING MOULD GROWTH



Testing for Resistance to Acidified Water (Flat and Corrugated Sheets)

The following reagents will be used for this test.

i. Acetic acid 5% (m/m) solution
ii. Sodium Hydroxide; 0.5M standard volumetric solution
iii. Thymol blue solution (dissolve 0.04g of thymol blue in 100 ml of 95 % (v/v) ethanol)

Initially two specimens with the dimensions of 65mm x 65mm will be cut from each of the sheets from the sample. To determine the concentration of the acetic acid solution, 10 drops of thymol blue solution will be added to 10ml solution of the acetic acid solution and will be diluted to 100ml while stirring. The solution will be titrated with the sodium hydroxide solution until the colour changes from yellow to blue which corresponds to a modification of the pH 8.0-9.5. The volume of the sodium hydroxide solution used for the titration will be recorded in ml (V1).

After determining the concentration of the acetic acid, the test specimen will be fully submerged in 270 ml of 5% acetic acid solution at a temperature of 27^{o}C ± 3 for 24 hours. Separate vessels and solution will be used to test each specimen. After 24 hours, the specimen will be removed and 10 drops of thymol blue solution will be added to 10ml of the solution and will be diluted to 100 ml. Again the solution will be titrated with sodium hydroxide and the volume required will be recorded in ml (V2). The amount of acetic acid used per m^2 of area of the specimen will be calculated from the following formula:

Amount of acid used in kg/m^2 = $\frac{\mathbf{0.030\ X\ 270\ (V1-V2)}}{\mathbf{10^4 X\ Area\ (m^2)}}$

TEST RESULTS: RESISTANCE TO ACIDIFIED WATER

Preparation of Acid

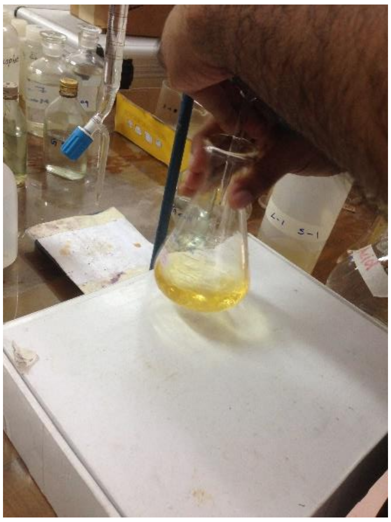


Figure 6: Conducting Acid Rain Test

SAMPLE	V1	V2	AREA	AMOUNT OF ACID CONSUMED
Non Asbestos 1	16.80 ml	6.80 ml	0.004225 m2	**1.91715976331 Kg/m2**
Non Asbestos 2	16.80 ml	6.30 ml	0.004225 m2	**2.01301775148 Kg/m2**
Non Asbestos 3	16.80 ml	6.20 ml	0.004225 m2	**2.03218934911 Kg/m2**
Asbestos 1	16.80 ml	5.30 ml	0.004225 m2	**2.20473372781 Kg/m2**
Asbestos 2	16.80 ml	5.30 ml	0.004225 m2	**2.20473372781 Kg/m2**
Asbestos 3	16.80 ml	5.20 ml	0.004225 m2	**2.22390532544 Kg/m2**

ISO 8336:2009 International Standards

Lists of tests need to be done

1) Dimensional conformity
    a) Textured fibre Cement sheet
        i) **Length and width**
        ii) **Thickness**
        iii) **Straightness of edges**
    b) Asbestos Flat Sheets
        i) **Length and width**
        ii) **Thickness**
        iii) **Straightness of edges**
2) Modulus of rupture (Bending strength)
    a) **Fibre Cement**
    b) **Asbestos Flat Sheets**
3) Moisture Movement
    a) **Fibre Cement**
    b) **Asbestos Flat Sheets**
4) Water permeability
    a) **Fibre Cement**
    b) **Asbestos Flat Sheets**
5) Freeze-thaw performance
    a) **Fibre Cement**
    b) **Asbestos Flat Sheets**
6) Heat-rain performance
    a) **Fibre Cement**
    b) **Asbestos Flat Sheets**
7) Warm water performance
    a) **Fibre Cement**
    b) **Asbestos Flat Sheets**
8) Soak-dry performance
    a) **Fibre Cement**
    b) **Asbestos Flat Sheets**
9) Resistance to mould
    a) **Fibre Cement**
    b) **Asbestos Flat Sheets**
10) Resistance to nail head pull-through
    a) **Fibre Cement**
    b) **Asbestos Flat Sheets**

Dimensional measurement and geometrical testing procedure

General

This annex gives the details of the measuring apparatus and measuring procedure which are to be used for the determination of compliance with the requirements of this International Standard.

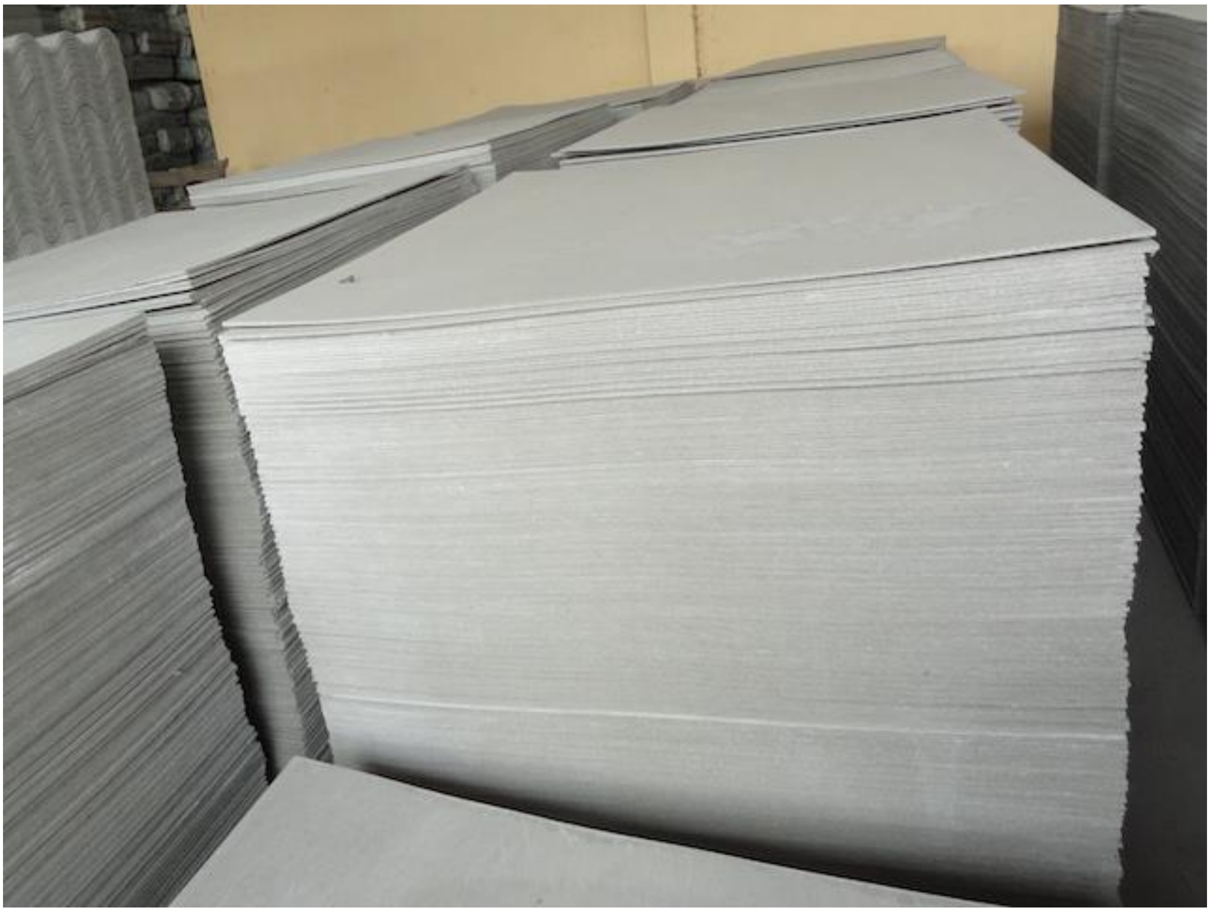


Figure 7: Flat Sheets dimensions

Principle

Sample sheets, selected from batches of sheets, are measured to determine their compliance with the length, width and thickness requirements of this International Standard.

Apparatus

The apparatus shall include the following items.

- **Inspection surface**, smooth, flat, rigid, of standard quality, having dimensions appropriate to the size of the sheets being measured.
- Two metal rules shall be fixed at right angles along adjacent edges of the inspection surface. The straightness of each metal rule shall be at least 0,3 mm/m and the right angle shall be accurate to at least 0,1 % (less than 1 mm deviation from normal per metre of length) or 0,001 rad.
- Alternatively, a portable square of at least 1 000 mm in each direction shall be used. The same requirements for straightness and angularity apply.

Rules, short, metal, capable of being read to an accuracy of 0,5 mm.

Measuring tape, metal, of sufficient length to measure the length of a sheet to an accuracy of 1 mm.

Dial gauge, reading to at least 0,1 mm, with flat parallel metal jaws between 10 mm and 15 mm in diameter.

Measuring procedure

Measurement of length and width

General

Avoid taking the measurement over a local deformation which could be considered as a visual defect. Smooth any rough areas.

Take each dimensional reading to the nearest 1 mm.

Measure each dimension three times on each sheet, i.e. one in the middle and one at about 50 mm from either end.

Measurement of Sheets

For large-sized sheets make three thickness measurements, with a dial gauge, along one side of the sheet taking each reading to an accuracy of 0, 1 mm, as indicated in Figure 3. Report the individual results and calculate the arithmetic mean and difference between extreme values.

For small-sized sheets, make two measurements with a dial gauge on each sheet, approximately 20 mm from the edge in the middle of two adjacent sides.

Report the individual results and calculate the arithmetic mean and difference between extreme values.

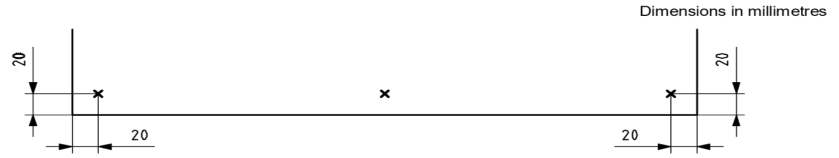


Figure 8: Measurement of thickness on large-sized non-textured sheets

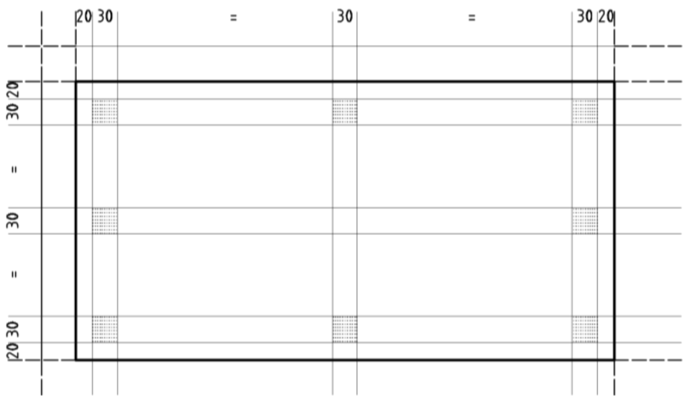


Figure 9: Measurement of thickness of large textured sheets

Measurement of edge straightness

For large-sized sheets measure on all four edges the greatest distance between the edge of the sheet and a string or wire stretched from one corner to the adjacent corner with a steel rule.

Record the measured value.

TEST RESULTS: RECORD THE MEASURED VALUE

Figure 10: Preparing full sheets for taking dimensions.

MEASUREMENT OF LENGTH AND WIDTH OF ASBESTOS FLAT SHEETS

Dimensions

1.0	Minimum Length/Width	122cm
2.0	Maximum Length/Width	122cm
3.0	Average Length/Width	122cm

MEASUREMENT OF LENGTH AND WIDTH OF CEMENT FIBER FLAT SHEETS

Dimensions

1.0	Minimum Length/Width	122cm
2.0	Maximum Length/Width	122cm
3.0	Average Length/Width	122cm

MEASUREMENT OF THICKNESS OF ASBESTOS FLAT SHEETS

Thickness

1.0	Minimum Thickness	4.6mm
2.0	Maximum Thickness	5.6mm
3.0	Average Thickness	5.0mm

MEASUREMENT OF THICKNESS OF CEMENT FIBER FLAT SHEETS

Thickness

1.0	Minimum Thickness	2.9 mm
2.0	Maximum Thickness	3.96 mm
3.0	Average Thickness	3.14mm

Measurement of flat sheet square ness

Place two adjacent corners of the sheet in succession between the arms of the square keeping one edge against the full length of the large arm and the other in contact with the small arm at least one point.

In this position measure to the nearest 0,5 mm the greatest distance of the sheet edge from the small arm of the square. Record the measured value.

TEST RESULTS FOR OUT OF SQUARENESS

CRYSTALLITE ASBESTOS FLAT SHEETS

	Sample 1	Sample 2	Sample 3	Average
A				
B				

FIBER CEMENT FLAT SHEETS

	Sample 1	Sample 2	Sample 3	Average
A	17.92	16.17	18.36	
B	21.1	17.46	16.53	

Modulus of rupture (bending strength)

General

This annex gives a method for determining the modulus of rupture for fibre-cement sheets.

Principle

A specimen is cut from a sample sheet and subjected to a flexural bending load until failure occurs, the failure load and specimen thickness are recorded. This test is repeated on the specimen with the bending mode at right angles to the initial test. The average modulus of rupture for the material is calculated from the test results.

Apparatus

Bending testing machine, which shall apply a load at a constant rate of deflection with an error of accuracy and an error of repeatability of 3 % comprising:

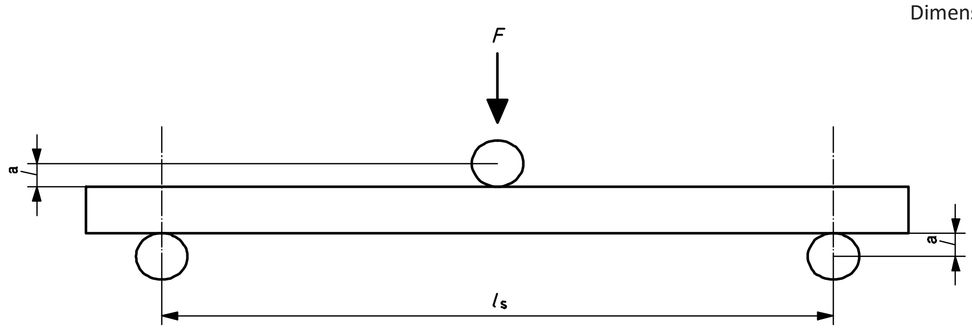
two parallel horizontal supports, one fixed and the second free to move to permit alignment with the specimen. The upper face of each support shall be rounded and shall have a radius between 3 mm and 25 mm (see Figure 11).

a loading bar having the same edge radius as the supports, located parallel to and equidistant from the supports. The loading bar is attached to the loading mechanism through a flexible connection.

The lengths of the supports and loading bar shall be greater than the width of the test specimen.

D.3.2 Micrometer, reading to an accuracy of at least 0,05 mm, with flat parallel metal jaws between 10 mm and 15 mm in diameter.

Dimensions in millimetres



[a] 3 mm to 25 mm.

*Figure 11— **Bending test configuration***

Specimen preparation

Prepare specimens to conform with the dimensional requirements of the referring standard (see 7.3.1) and condition samples prior to testing as appropriate for the sheet category (see Table 11).

Test procedure

a) Arrange the supports to be at the appropriate spacing for the specimen.

NOTE This is normally 200 mm between bar centres, but can be altered according to the specimen characteristics (see 7.3.1.3.3).

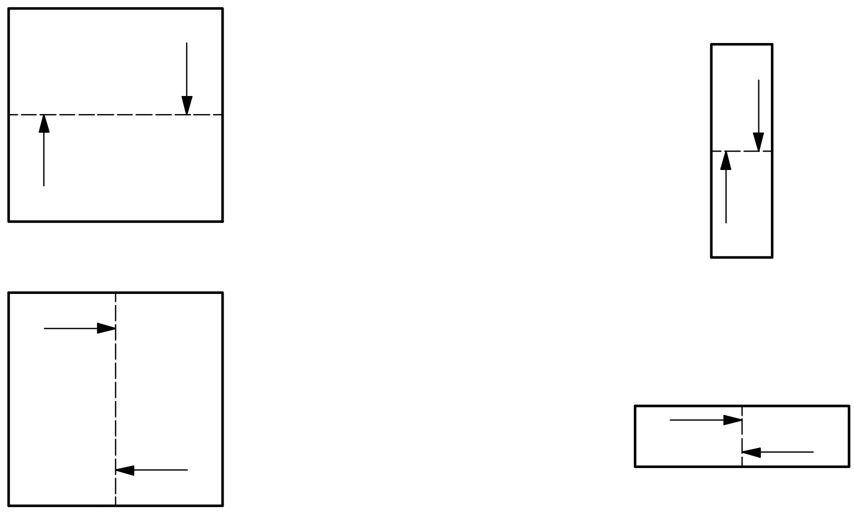
b) Measure the thickness of the sheet along the imaginary line of breakage (see Figure D.2). Measure smooth sheets at two points. For textured sheets, measure the thickness of the sheet by calculating the water displacement. Alternative methods for determination of average thickness of textured product may be used provided that they can be proven, on average, to yield a thickness measurement within plus or minus 2% of that determined from the volume measurement by water displacement.

c) Arrange the specimen with the under face against the supports and the loading bar on the upper face equidistant between and parallel with the supports.

d) Load the specimen such that the breakage occurs within 10 s and 30 s. A constant rate of deflection is preferred; if this cannot be achieved a constant rate of loading is acceptable. Record load at break.

e) For square specimens, re-assemble the broken pieces and submit the specimen to a second bending test with the line of load application at right angles to that of the first test. Record load at break.

NOTE Where rectangular specimens are being used, the strengths in two directions are obtained by testing each of the appropriate specimens (see Figure D.2).



a) Square specimens b) Rectangular specimens

Figure D.2 — Measurement of thickness specimens

Calculation of modulus of rupture value

The MOR, in mega pascals, for each breaking load direction is given by Equation (D.1):

$$\text{MOR} = \frac{3Fl_s}{2be^2} \qquad \text{(D.1)}$$

where

F is the breaking load, in newtons;

l_s is the span between the centre-lines of the supports, in millimetres;

b is the width of the test piece, in millimetres;

e is the thickness, in millimetres.

for non-textured sheets, it is the arithmetic mean of two measurements for each breaking load direction, for face textured sheets, it is calculated from the volume measured by water displacement. The MOR of the sheet(s) shall be the arithmetic mean of the five (ten) values (two values in each direction).

For initial type tests, to determine product class where production variance is unknown, an estimate of the mean MOR at the 95 % confidence level shall be determined. This shall be done by taking one square sample or two rectangular samples from a minimum of ten individual sheets, and carrying out the following procedure:

e) For each sheet calculate MOR_i as the average of MOR along and MOR across for the i^{th} sheet;

f) Calculate the mean, R_i, and the standard deviation, s, of the combined average MOR_i values;

g) Calculate the mean, R_{cl}, of the MOR_i values at the 95 % confidence level using Equation (D.2):

$$R_{cl} \; R_i \; 0{,}58s \qquad \text{(D.2)}$$

(See ISO 2602.)

h) Determine the product class by comparing the R_{cl} value with the category and minimum class requirement in Table 7 (R_{cl} W Table 7 value).

TEST RESULTS: RECORDED BENDING STRENGTH OF FIBER CEMENT FLAT SHEETS

Figure 12: Recording Bending strength of flat sheets

MODULUS OF RUPTURE (BENDING STRENGTH) OF CHRYSTALITE FLAT SHEETS

Breaking Load		LS	B	E	MOR
Sample 1A	447.1N	200.0mm	250.0mm	4.9mm	22.62
Sample 1B	298.8N	200.0mm	250.0mm	4.6mm	16.87
Sample 2A	349.7N	200.0mm	250.0mm	5.3mm	14.94
Sample 2B	654.0N	200.0mm	250.0mm	5.0mm	31.90
Sample 3A	224.4N	200.0mm	250.0mm	4.1mm	15.94
Sample 3B	350.6N	200.0mm	250.0mm	3.7mm	30.40
Sample 4A	229.2N	200.0mm	250.0mm	4.3mm	14.88
Sample 4B	428.0N	200.0mm	250.0mm	4.3mm	27.78
Sample 5A	236.7N	200.0mm	250.0mm	4.6mm	13.54
Sample 5B	407.9N	200.0mm	250.0mm	4.8mm	21.25
Sample 6A	197.8N	200.0mm	250.0mm	4.0mm	14.69
Sample 6B	352.9N	200.0mm	250.0mm	4.4mm	21.48
Sample 7A	240.2N	200.0mm	250.0mm	4.7mm	13.11
Sample 7B	376.9N	200.0mm	250.0mm	4.8mm	19.47
Sample 8A	217.6N	200.0mm	250.0mm	4.5mm	13.07
Sample 8B	437.1N	200.0mm	250.0mm	4.6mm	24.90

FINAL RESULTS OF BREAKING LOAD

Strong side Average	**431.8125**	**200**	**250**	**4.5625mm**	**24.975**
Weak side Average	**249.3**	**200**	**250**	**4.5125**	**14.63**

TEST RESULTS: RECORDED BENDING STRENGTH OF CHRYSTALITE FLAT SHEETS

Figure 13: Recording Bending strength of flat sheets

MODULUS OF RUPTURE (BENDING STRENGTH) OF CEMENT FIBER FLAT SHEETS

	Breaking Load	LS	B	E	MOR
Sample 1A	117.5N	200.0mm	250.0mm	3.1mm	14.76
Sample 1B	75.8N	200.0mm	250.0mm	3.12	9.35
Sample 2A	121.1N	200.0mm	250.0mm	3.2mm	14.55
Sample 2B	71.0N	200.0mm	250.0mm	3.12	8.76
Sample 3A	122.3N	200.0mm	250.0mm	3.2mm	14.70
Sample 3B	76.8N	200.0mm	250.0mm	3.12	9.47
Sample 4A	122.2N	200.0mm	250.0mm	3.2mm	14.50
Sample 4B	74.2N	200.0mm	250.0mm	3.18	8.80
Sample 5A	120.3N	200.0mm	250.0mm	3.12	14.83
Sample 5B	70.7N	200.0mm	250.0mm	3.29	7.87
Sample 6A	119.6N	200.0mm	250.0mm	3.19	14.10
Sample 6B	70.7N	200.0mm	250.0mm	3.13	8.66
Sample 7A	119.7N	200.0mm	250.0mm	3.04	15.54
Sample 7B	75.6N	200.0mm	250.0mm	3.08	9.57
Sample 8A	122.6N	200.0mm	250.0mm	3.19	14.46
Sample 8B	72.6N	200.0mm	250.0mm	3.18	8.62

FINAL RESULTS OF BREAKING LOAD

Strong side Average	120.7N	200.0mm	250.0mm	3.1mm	14.68
Weak side Average	73.4N	200.0mm	250.0mm	3.2mm	8.89

Density of fiber-cement sheets

General

This annex gives the test method for determination of the apparent density (see 3.4) of fibre-cement sheets. This is the average density of the material and its pores.

Principle

The volume of a saturated specimen is determined by immersion in water. The specimen's oven dry weight is then measured. The apparent density is determined by calculation from the measured values.

Apparatus

Oven, ventilated, capable of achieving a temperature of (100 5) °C with a full load of specimens.

Balance, accurate to within 0,1 % of the specimen mass, equipped to determine both the immersed mass and the non-immersed mass of the specimen.

Test procedure

e) Immerse specimen in water. Specimens having a thickness u 20 mm shall be immersed for at least 24 h.

f) Specimens having a thickness 20 mm shall be immersed for at least 48 h.

g) Take saturated specimen, remove excess water from surfaces and then determine the volume of the water displaced, V, by the saturated specimen when placed into a water bath. Record this value.

h) Remove specimen from water bath and place it into a ventilated oven which is maintained at a temperature of (100 5) °C until constant mass, m, is reached. (i.e. mass gain in any 24 h period does not exceed 0,1 % of specimen weight). Record this value.

Calculation of apparent density

The apparent density, d, in grams per cubic centimeter, is given by Equation (E.1):

$$d \quad \frac{m}{V}$$ (E.1)

where m is the mass of the specimen

after drying;

V is the volume of the specimen, in cubic centimetres.

TEST RESULTS – DENSITY

Figure 14: Recording density of flat sheets

DENSITY CHRYSTALITE FLAT SHEETS

Asbestos	Water Displacement	Dry Weight	Density
Sample 1	0.0002698m3	0.4480Kg	1660.61 Kg/m3
Sample 2	0.0002580m3	0.4142Kg	1605.26 Kg/m3
Sample 3	0.0002673m3	0.4354Kg	1628.95 Kg/m3
Sample 4	0.0002807m3	0.4655Kg	1658.33 Kg/m3
Sample 5	0.0002529m3	0.4140Kg	1636.84 Kg/m3
Sample 6	0.0002991m3	0.4705Kg	1573.26 Kg/m3
Sample 7	0.0002703m3	0.4317Kg	1597.37 Kg/m3
Sample 8	0.0003676m3	0.6159Kg	1675.68 Kg/m3
Sample 9	0.0003609m3	0.5746Kg	1592.31 Kg/m3
Sample 10	0.0003251m3	0.5381Kg	1655.26 Kg/m3
Average			**1628.39 Kg/m3**

DENSITY FIBER CEMENT FLAT SHEETS

Fiber cement	Water Displacement	Dry Weight	Density
Sample 1	0.0002320m3	0.2772Kg	1194.97 Kg/m3
Sample 2	0.0002530m3	0.2747Kg	1085.69 Kg/m3
Sample 3	0.0002408m3	0.2776Kg	1152.78 Kg/m3
Sample 4	0.0002031m3	0.2732Kg	1345.15 Kg/m3
Sample 5	0.0002387m3	0.2741Kg	1148.25 Kg/m3
Sample 6	0.0001926m3	0.2774Kg	1439.96 Kg/m3
Sample 7	0.0002068m3	0.2836Kg	1371.27 Kg/m3
Sample 8	0.0001824m3	0.2828Kg	1550.52 Kg/m3
Sample 9	0.0001969m3	0.2843Kg	1444.22 Kg/m3
Sample 10	0.0001654m3	0.2729Kg	1649.46 Kg/m3
Average			**1338.23 Kg/m3**

Moisture movement characteristic of fibre-cement sheets

General

This annex gives the details of the apparatus and test procedure required to determine the moisture movement characteristic of fibre-cement sheets.

Principle

The lengths of sheet specimens, conditioned in air at the prescribed temperature and relative humidity, are measured when a steady weight condition is achieved. The specimens are then exposed to a higher relative humidity until a second steady weight condition is reached. The change in length which occurs is measured.

Apparatus

Conditioning chamber, ventilated, capable of maintaining a temperature of (23, ±2)°C at relative humidifies of either (30 ±2) % or (90, ±5) % with a full load of specimens. **F.3.2 Balance**, accurate to within 0,1 % of the specimen mass.

Measuring device, metal, of sufficient length to measure the length of the specimen to an accuracy of 0,02 mm.

Specimen preparation

Prepare specimens to conform with the dimensional requirements of the referring standard (see 7.3.3.3) and condition samples prior to testing

Test procedure

a) Remove specimens from conditioning chamber and measure their lengths and weights and record values.

b) Replace specimens in conditioning chamber, increase humidity to (90, ±5) % maintaining temperature at (23, ± 2) °C.

c) When specimens have reached a steady state condition (i.e. weight gain or loss in any 24 h period does not exceed 0,1 % of specimen mass) reweigh specimens and measure their lengths. Record values.

Calculation of results

The linear, L_m, expressed as a percentage, due to a change in the moisture is calculated from Equation (F.1):

$$\% \quad \frac{(L_{90} \quad L_{30})\,100}{L_{30}}$$

where

L_{90} is the measured specimen length at 90 % relative humidity; L_{30} is the measured specimen length at 30 % relative humidity.

Water permeability of fibre-cement sheets

General

This annex gives details of the test procedure and apparatus required to determine that sheets of fibre cement comply with the water permeability requirements of this International Standard (see 5.6.5).

Principle

A specified depth of water is applied to the upper face of a horizontally positioned sheet specimen for a prescribed period of time. Visual examination of the test specimen determines compliance with standard requirements.

Apparatus

G.3.1 Frame, sealed on top of the sheet specimen.

For small-sized sheets, the frame shall be 50 mm less than the length and width of the sheet. For large-sized sheets, the frame dimensions shall be 600 mm 500 mm. A narrow frame of the same length shall be used for narrow sheets.

Test procedure

a) Place and seal the frame to the top face of the sheet and position so that sheet face is horizontal.

b) Fill the frame with water to a height of 20 mm above the sheet face.

c) Place the specimen in ambient laboratory conditions so that the underside of the sheet can be viewed without moving the specimen during the test.

d) After 24 h examine the under face for the presence of water drops. Report the visual condition of the specimen.

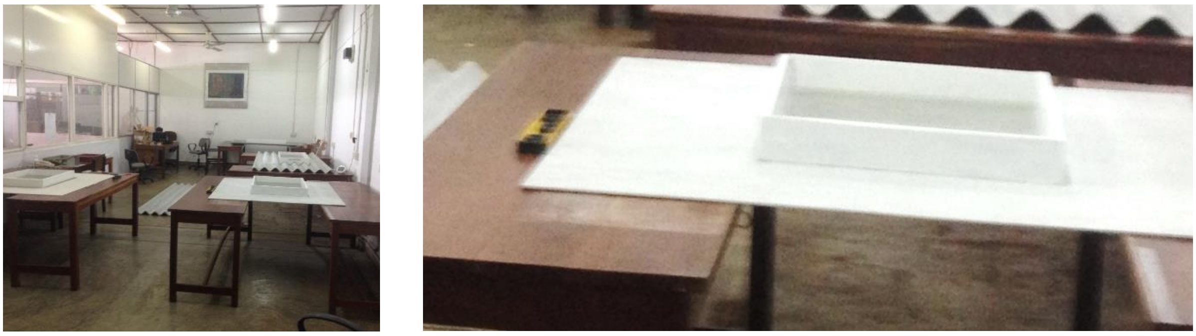


Figure 15: Checking water permeability

TEST RESULTS – WATER PERMEABILITY TEST

- No water droplets were examined after 24 hours

Soak-dry evaluation test of fibre-cement sheets

General

This annex gives the details of the apparatus and test procedure required to perform the soak-dry evaluation test for fibre-cement sheets.

Principle

Paired fibre-cement sheet specimens are taken from sample sheets. One of each specimen pair is subjected to a number of test cycles comprising a period of immersion in warm water and drying in an oven. A comparison of the bending strengths of the specimens exposed to soak-dry test cycling to the unexposed specimens is made.

Apparatus

Oven, ventilated, capable of maintaining a temperature of (60±3) °C at a relative humidity of less than 20 % with a full load of specimens.

Water bath, with water at ambient temperature (5 °C).

The water in the water bath should be saturated with soluble salts derived from the fibre-cement sheets. **Test equipment**, for determining the bending strength.

Test procedure

a) Divide the sheet specimen pairs (see 7.3.7.2) to form two sets of 10 specimens each.
b) Condition one set of 10 specimens to the appropriate sheet category type test conditioning requirements specified in Table 11. Following the conditioning period, determine the bending strengths of these specimens in accordance with the test method given in Annex D. Record the results.
c) Immerse the second set of 10 specimens in the water bath and commence the soak-dry test cycle.
d) A soak-dry test cycle shall consist of
    a. immersion in water at ambient temperature (5 °C) for 18 h,
    b. drying in a ventilated oven at (60±3) °C and a relative humidity of less than 20 % for 6 h. The 20 % humidity shall be achieved for at least 3 h prior to the conclusion of the drying period.
    c. If necessary, an interval of up to 72 h between cycles is allowed. During this interval, specimens shall be stored in immersed conditions.
e) Repeat step c) for the prescribed number of soak-dry cycles appropriate for the category of sheet being tested.
f) The value of the ratio, R_L, of the lower estimate mean values of the modulus of ruptures for the exposed and unexposed specimens, shall be determined for category A sheets after 50 soak-dry cycles and for categories B and C sheets after 25 soak-dry cycles.
g) When step d) has been completed, condition the immersed specimens to the appropriate sheet category type test conditioning requirements specified in Table 11, then determine the bending strengths of these specimens in accordance with the test method given in Annex D. Record the results.

Calculation of results

For each pair of specimens i (i 1 to 10), calculate the individual ratio, MORi, as given in Equation (K.1):

$$MOR_i = \frac{MOR_{fi}}{MOR_{fci}} x\ 100$$

where

- MOR_{fi} is the modulus of rupture of the i^{th} specimen after the soak dry cycles;
- MOR_{fci} is the modulus of rupture of the i^{th} reference specimen (from the first batch).

Calculate the average, R, and standard deviation, s, of the individual ratio, MOR_i.

Calculate the lower estimation, R_L, of the mean of the ratios at 95 % confidence level (see ISO 2602) as given in Equation (K.2):

$R_L R$ 0,58s

TEST RESULTS – SOAK DRY CYCLES

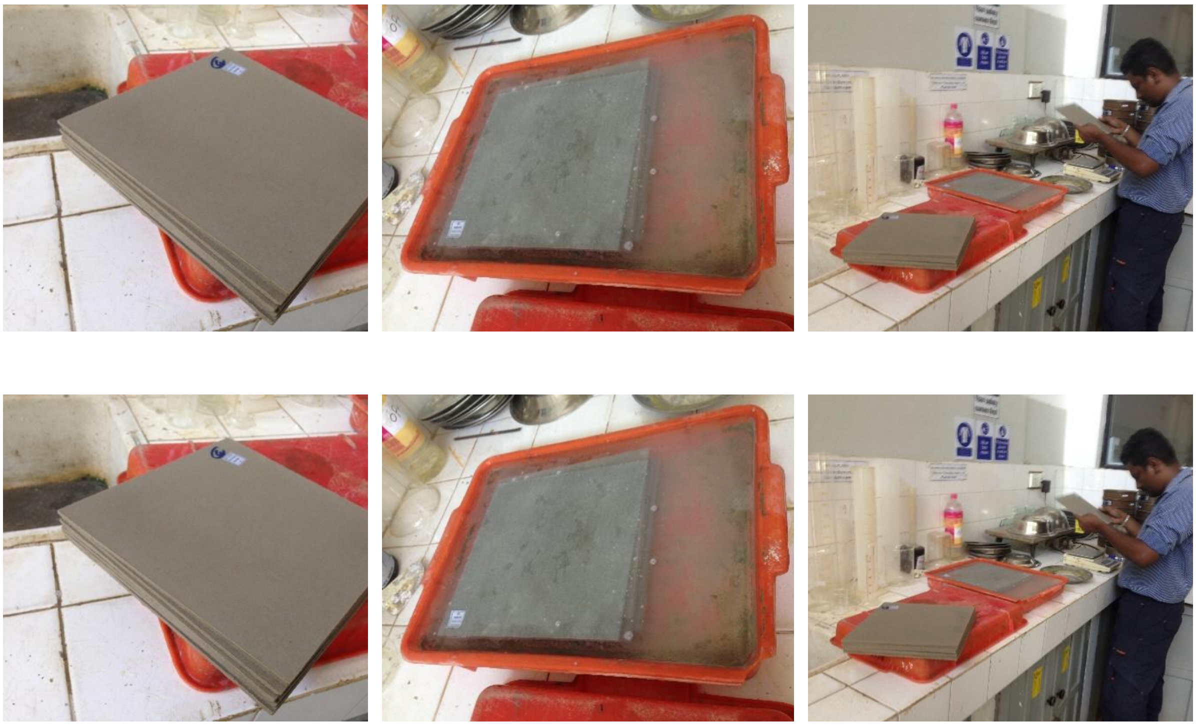


Figure 16: Recording Bending strength of flat sheets

MODULUS OF RUPTURE (BENDING STRENGTH) OF CHRYSTALITE ASBESTOS SHEETS (REF

	Breaking Load	LS	B	E	MOR
Sample 1A	447.1	200	250	4.450mm	**27.09N/mm2**
Sample 1B	298.8	200	250	4.500mm	**17.71N/mm2**
Sample 2A	654	200	250	4.250mm	**43.45N/mm2**
Sample 2B	349.7	200	250	4.300mm	**22.70N/mm2**
Sample 3A	350.6	200	250	4.150mm	**24.43N/mm2**
Sample 3B	224.4	200	250	4.000mm	**16.83N/mm2**
Sample 4A	428	200	250	4.000mm	**32.10N/mm2**
Sample 4B	229.2	200	250	4.200mm	**15.59N/mm2**
Sample 5A	407.9	200	250	4.700mm	**22.16N/mm2**
Sample 5B	236.7	200	250	4.650mm	**13.14N/mm2**
Sample 6A	352.9	200	250	4.450mm	**21.39N/mm2**
Sample 6B	197.8	200	250	4.500mm	**11.72N/mm2**
Sample 7A	376.9	200	250	4.250mm	**25.04N/mm2**
Sample 7B	240.2	200	250	4.300mm	**15.59N/mm2**
Sample 8A	437.1	200	250	4.150mm	**30.46N/mm2**
Sample 8B	217.6	200	250	4.000mm	**16.32N/mm2**
Strong side Average					**28.26N/mm2**
Weak side Average					**16.20N/mm2**

SOAK DRY RESULTS - MODULUS OF RUPTURE

	Breaking Load	LS	B	E	MOR
Sample 1A	441.0N	200.0mm	250.0mm	4.900mm	**26.72N/mm²**
Sample 1B	170.0N	200.0mm	250.0mm	4.600mm	**10.07 N/mm²**
Sample 2A	423.0N	200.0mm	250.0mm	5.000mm	**28.10N/mm2**
Sample 2B	198.0N	200.0mm	250.0mm	5.300mm	**12.85N/mm2**
Sample 3A	478.0N	200.0mm	250.0mm	3.700mm	**33.31N/mm2**
Sample 3B	142.0N	200.0mm	250.0mm	4.100mm	**10.65N/mm2**
Sample 4A	534.0N	200.0mm	250.0mm	4.300mm	**40.05N/mm2**
Sample 4B	198.0N	200.0mm	250.0mm	4.300mm	**13.47N/mm2**
Sample 5A	618.0N	200.0mm	250.0mm	4.800mm	**33.57N/mm2**
Sample 5B	254.0N	200.0mm	250.0mm	4.600mm	**14.10N/mm2**
Sample 6A	560.0N	200.0mm	250.0mm	4.400mm	**33.94N/mm2**
Sample 6B	162.0N	200.0mm	250.0mm	4.000mm	**9.60N/mm2**
Sample 7A	558.0N	200.0mm	250.0mm	4.800mm	**37.07N/mm2**
Sample 7B	202.0N	200.0mm	250.0mm	4.700mm	**13.11N/mm2**
Sample 8A	470.0N	200.0mm	250.0mm	4.600mm	**32.75N/mm2**
Sample 8B	140.0N	200.0mm	250.0mm	4.500mm	**10.50N/mm2**
Strong side Average					**33.19N/mm²**
Weak side Average					**11.79N/mm2**

FINAL RESULTS OF SOAK DRY CYCLES

$$MOR_i = \frac{MOR_{fi}}{MOR_{fci}} X\ 100$$

- MOR_{fi} is the modulus of rupture of the i^{th} specimen after the soak dry cycles;
- MOR_{fci} is the modulus of rupture of the i^{th} reference specimen (from the first batch).

STRONG SIDE

$$MOR_i = \frac{33.19N/mm2}{28.26N/mm2} X\ 100 = \underline{117.42\%}$$

WEAK SIDE

$$MOR_i = \frac{11.79N/mm2}{16.20N/mm2} X\ 100 = \underline{137.35\%}$$

Test method for the evaluation of heat-rain performance of fibre-cement sheets

General

This annex gives the details of the apparatus and test procedure required to evaluate the heat-rain performance of fibre-cement sheets.

Principle

Sample sheets are fixed to a framing system to simulate a typical sheet installation system. One side of the test assembly is subjected to a number of test cycles comprising a water spray and radiant heating. A visual assessment of the sheet performance is made.

Apparatus

Framing system, to which sheets can be fixed in a vertical position.

Spacing of framing members and type of material used shall be specified by the manufacturer (see Clause I.4).

Water spray system, capable of completely wetting the sheet faces, having a water flow rate of approximately 1 l/m^2/min.

Device, capable of heating and uniformly maintaining the surface of the test elements conforming to the following:

a) The heating device shall be controlled via a black body sensor positioned in the central area of the test rig where the maximum temperature is expected.

b) The temperature at the sensor location shall be maintained at (60 3) °C and this temperature shall be reached within 15 min of the commencement of heating.

c) The difference between the black body temperature in the centre of the rig and the edges of the rig shall not exceed 15 °C.

Control system, capable of providing test cycles complying with Table I.1.

Framing and fixing requirements

Frame requirements

The frame construction shall include at least one joint in the central region and allow for standard size sheet fixing.

The frame shall provide a minimum area of 3,5 m^2 and a maximum area of 12 m^2, shall allow vertical orientation of the sheets and shall allow for the installation of at least two sheets.

Specimen requirements

Where the sheet specimen is greater than 1,8 m^2, two sheets may be used.

Where the sheet specimen is not greater than 1,8 m^2, there shall be sufficient sheets to cover an area of at least 3,5 m^2.

NOTE If the combined area of the specimens is 12 m^2, the sheet length can be reduced to provide a test area of not more than 12 m^2.

Test procedure

a) Assemble the test rig in accordance with the manufacturer's recommendations.

b) Subject the assembled frame to the water spray and drying cycle given in Table I.1.

Table 1 ***— Heat-rain cycle***

Cycles	Duration
Water spray Pause	2 h 50 min 5 min 5 min to 10 min
Radiant heat Pause	2 h 50 min 5 min 5 min to 10 min
Total cycle	5 h 55 min 15 min

c) Repeat step b) for the prescribed number of cycles appropriate to the category of sheet. Assemblies made with category A sheets shall be tested for 50 heat-rain cycles. Assemblies made with category B sheets shall be tested for 25 heat-rain cycles.

d) Visually inspect the test assembly and record its condition.

[redacted]

TEST RESULTS – SOAK DRY CYCLES

Figure 17: Heat Rain test

MODULUS OF RUPTURE (BENDING STRENGTH) OF CHRYSTALITE ASBESTOS SHEETS (REF

Asbestos	230mm wood plate	steel	Hydraulic Jack	Proving Ring	Measured Value	Measured Load	Breaking Load			Asbestos			
							F	b	ls	Heat Rain		Before heat rain	
Sample 1	69.2N	1.5N	49.1N	21.9N	48	2580.0N	2722N	1095	2397	5416.01N/mm2	993N	6391.72N/mm2	1172N
Sample 2	69.2N	1.5N	49.1N	21.9N	46	2420.0N	2562N	1095	2397	5097.60N/mm2	935N	5945.95N/mm2	1090N
Sample 3	69.2N	1.5N	49.1N	21.9N	52	2740.0N	2882N	1095	2397	5734.41N/mm2	1051N	6503.16N/mm2	1192N
Average							**2722N**	1095	2397	5416.01N/mm2	993N	6280.28N/mm2	1151N
										Fiber Cement			
Fiber Cement	**230mm wood plate**	**steel**	**Hydraulic Jack**	**Proving Ring**	**Measured Value**	**Measured Load**	F	b	ls	**Heat Rain**		**Before heat rain**	
Sample 1	69.1605	1.5N	49.05	21.9N	24	1295	1437N	940	1700	2361.85N/mm2	433N	2702.67N/mm2	495N
Sample 2	69.1605	1.5N	49.05	21.9N	22	1140	1282N	940	1700	2107.01N/mm2	386N	2932.84N/mm2	538N
Sample 3	69.1605	1.5N	49.05	21.9N	24	1295	1437N	940	1700	2361.85N/mm2	433N	2794.74N/mm2	512N
Average							**1385N**	940	1700	2276.90N/mm2	417N	2810.08N/mm2	515N

Testing for Mould Growth

General

Three Specimens with a size of 50mm x 50mm will be cut from the sample sheet. A spore suspension will be prepared with accordance to ASTM G21. Initially nutrient-salts agar will be poured into suitable sterile dishes to create a solidified agar layer with 3-6mm depth. After the agar is solidified the specimens will be placed on the agar surface and the whole surface including the test specimen surface will be inoculated with the spore suspension by spraying from a sterilized atomizer with 110kPa air pressure. The test specimens will be covered and will be incubated at 28-30^{o}C and not less than 85% of humidity for a minimum of 21 days. The growth will be recorded each day.

Principle

If the test is done for visible effects only, then the three specimens will be removed from the incubator and the mould growth will be observed and will be rated according to the following:

Observed Growth Specimen	Rating
None	0
Traces of growth (Less than 10%)	1
Light Growth (10%-30%)	2
Medium Growth (30%-60%)	3
Heavy Growth(60% to complete coverage)	4

Apparatus

Mould growth testing equipment and mould growing medium made of using required culture.

Test procedure

As physical changes might occur without considerable visible effects, the test specimens will be washed, immersed in aqueous solution of mercuric chloride for 5 min, rinsed in tap water, air dried overnight in room temperature and reconditioned at the laboratory standard conditions mentioned in ASTM D618 and will be tested according to the respected methods mentioned in the Appendix of ASTM G21 for effects on physical, optical or electrical properties.

TEST RESULTS APPARENT DENSITY

Crystallite sheets

Asbestos	Mould Growth Rate	Required standard	Test Summery	
Sample 1	5%	10%	Pass	Traces of growth (Less than 10%)
Sample 2	3%	10%	Pass	Traces of growth (Less than 10%)
Sample 3	2%	10%	Pass	Traces of growth (Less than 10%)
Average			Pass	Traces of growth (Less than 10%)

Cement fibre sheet material

Fiber Cement	Mould Growth Rate	Required standard	Test Summery	
Sample 1	45%	10%	Fail	Medium Growth (30%-60%)
Sample 2	68%	10%	Fail	Medium Growth (30%-60%)
Sample 3	80%	10%	Fail	Heavy Growth(60% to complete coverage)
Average			Fail	Medium Growth (30%-60%)

TESTING MOULD GROWTH



Nail Head Pull through test

A specimen with a size of 76mm x 152mm will be cut from the sample and a common wire nails with 2.8mm diameter will be driven through the board at right angles. Test machine will be assembled in a way as showed in figure 9 of the ASTM D1037.The top pair of angles of the specimen holding will be replaced with a 152mm length of 152 by 57 mm American Standard Channel. The web of the channel will have a 76mm diameter opening. The edge of this will support the specimen during the test. The specimen holding fixture will be centered and attached to the lower platen of the testing machine.

The specimen will be inserted in the fixture and with the point of the nail (2.8mm diameter) up. The pointed end of the nail will be gripped with a tension grip which is attached to the upper platen of the testing machine with a universal joint/toggle linkage, to provide automatic aligning. Loads will be applied to the specimen throughout the test at a uniform rate of 1.5mm/min, by a separation of the platens of the testing machine. The maximum load required to pull the nail through the board will be recorded. (ASTM- Part 22 D1037: 1981)

TEST RESULTS – NAIL HEAD PULL THROUGH TEST

Figure 18: NAIL HEAD PULL THROUGH TEST

TEST RESULTS - NAIL HEAD PULL THROUGH TEST

Asbestos	Breaking Load (Kg)	Breaking Load (N)	Results
Sample 1	46.895Kg	460.04 N	**Pass**
Sample 2	48.970Kg	480.40 N	**Pass**
Sample 3	49.356Kg	484.18 N	**Pass**
Average		**474.87 N**	**Pass**

Fiber Cement	Breaking Load (Kg)	Breaking Load (N)	Results
Sample 1	17.220Kg	168.93 N	**Fail**
Sample 2	18.725Kg	183.69 N	**Fail**
Sample 3	15.725Kg	154.26 N	**Fail**
Average		**168.96 N**	**Fail**

ISO 10904:2009 International Standards

Lists of tests need to be done

1) Dimensional and geometrical testing procedures
    a) **Length and width**
    b) **Measurement of the thickness of sheets**
    c) **Measurement of out-of-squareness of sheets**
    d) **Measurement of length and width for fittings**
    e) **Measurement of thickness for fittings**
2) Breaking load and the bending modulus of sheets
    a) **Fibre Cement**
    b) **Asbestos Flat Sheets**
3) Bending moment of a sheet
    a) **Fibre Cement**
    b) **Asbestos Flat Sheets**
4) Determine the apparent density
    a) **Fibre Cement**
    b) **Asbestos Flat Sheets**
5) Determine the water permeability of a sheet
    a) **Fibre Cement**
    b) **Asbestos Flat Sheets**
6) Freeze-thaw performance of sheets and fittings
    a) **Fibre Cement**
    b) **Asbestos Flat Sheets**
7) Soak-dry performance of long and short sheets
    a) **Fibre Cement**
    b) **Asbestos Flat Sheets**

Consignment and inspection sampling

General

This annex gives details of a system for inspecting and sampling a, consignment of finished products (see 6.4), that may, by agreement between the manufacturer and the purchaser, be included in a tender or product order.

NOTE Compliance with 6.4 is not a requirement of this International Standard

Sampling

When specified, the acceptance sampling shall be made on lot(s) of the consignment in accordance with the test programme of the relevant product standard, unless there is a special agreement. Table 6, therefore, specifies which characteristics are tested.

Details related to the application of this sampling sub clause shall be agreed between the manufacturer and purchaser.

After agreement on the sampling procedure, sampling shall be carried out in the presence of both parties, from lot(s) that are being delivered to the purchaser. If the inspection lot(s) are not yet formed, the manufacturer should present to the purchaser the stock(s) from which the inspection lot(s) can be selected and marked. Unless otherwise agreed between manufacturer and purchaser, the maximum and minimum inspection lots shall be as follows:

- sheets of length less than 1,5 m: minimum 400 sheets and maximum 8 000 sheets;
- sheets of length 1,5 m and greater: minimum 200 sheets and maximum 3 000 sheets;
- fittings: minimum 200 fittings and maximum 400 fittings.

Testing

The tests shall be made in the laboratory of the manufacturer or by an independent laboratory selected by mutual agreement between the manufacturer and the purchaser. In case of dispute, the tests shall be performed in the presence of both parties.

Non-destructive tests

When non-destructive tests are performed and the result of the sampling inspection does not meet the acceptance requirements of this International Standard, the tests shall be required on each item of the consignment. The units of the consignment that do not meet the requirements when tested individually may be refused and disposed of, unless otherwise agreed between manufacturer and purchaser.

Dimensional and geometrical testing procedures

General

The annex 'gives the details of the measuring apparatus and procedures that can be used for carrying out dimensional and geometrical measurements and the determination of compliance with the requirements of this International Standard.

Principle

Profiled sheets are measured to determine compliance with the requirements of this International Standard for pitch, height of corrugation, length, width, thickness, out-of-squareness and height of edges.

Fittings are measured to determine compliance with the requirements of this International Standard for length, width and thickness.

- Measurement of pitch and height of corrugation for sheets

Apparatus

- Surface, smooth, flat, with dimensions appropriate to the dimensions of the sheets.
- Bars, cylindrical, steel, 200 mm long, with. Conical points fitted at the axis on one end and with a diameter large enough to touch the flanks of the corrugations of the sheet.
- Micrometre, with a hemispherical head accurate to 0, 1 mm Ruler metal, graduated, accurate to 0, 6 mm.
- Procedure for measuring the pitch, a Lay the sheets flat and square on the surface (see Figure ensuring that the valley of every corrugation is in contact with it.

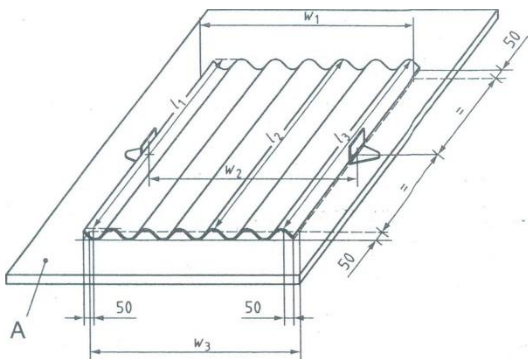


Figure 19:Measurement of the length and width

At one end of the sheet, lay the cylindrical bars in each valley of the corrugations, with the conical point extending slightly over the end of the sheet (see Figure 19).

Measure with the ruler, to the nearest 0,5 mm, the distance between consecutive conical points. Any other method of measurement with the same accuracy may be used.

Each measurement of the pitch shall be compared to the specification given (Figure 19). .

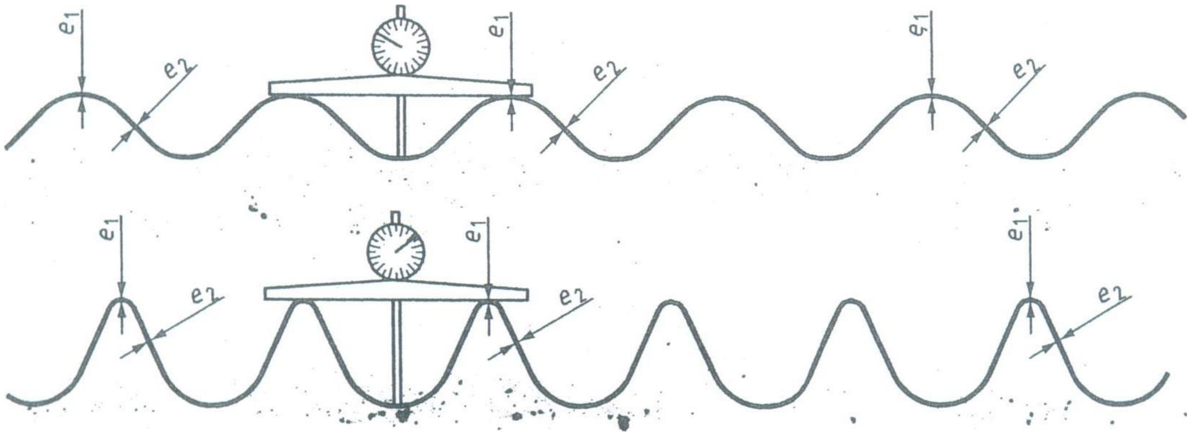


Figure 20: Measurement of the height of corrugations and thickness

Measurement of length and width of sheets

Apparatus

- **Surface,** smooth, flat, with dimension appropriate to the dimensions of the sheets.
- **Ruler,** graduated in millimetres.
- **Calliper blocks,** two, rectangular.

Procedure

Lay the sheet flat and square on the surface (see Figure B.1), ensuring that the valley of every corrugation is in contact with it.

To measure the length, take three measurements, one in the middle and one approximately 50 mm from each side, or further to avoid mirrored corners; see Figure B.1.

To measure the width of sheets longer than 0,9 m, take three measurements, one in the middle and one approximately 50 mm from each end, or further if necessary to avoid mired corners. For sheets of nominal length equal to or shorter than 0,9 m, take two measurements approximately 50 mm from each end; see Figure B.1.

Read each measurement to the nearest millimeter. Calculate the arithmetic average of the length and width and compare them with the specifications given.

Measurement of the thickness of sheets

Apparatus

- Micrometre, with hemi-cylindrical plates (see Figure 21), accurate to 0,05 mm.

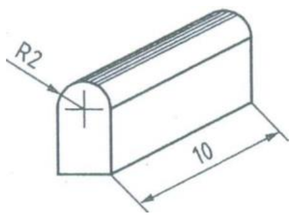


Figure 21: Hemi-cylindrical plate for measurement of thickness(Dimensions in millimeters)

Procedure

Take six measurements, to the nearest 0,1 mm, approximately 15 mm in from the end of each sheet as follows.

- For sheets of type a, take the measurements in three valleys and three crowns of the corrugation, as shown in Figure 22.
- For sheets of type B, take the **measurements on six sides** of the corrugations, as shown in Figure B.3 b).

Each individual measurement shall be compared with the appropriate minimum thickness specified, and the arithmetic average of the six measurements made on one sheet shall be compared with the specifications given.

Measurement of out of squareness of sheets

Surface, smooth, flat, with dimensions appropriate to the dimensions of the sheet.

Ruler, graduated, metal, accurate to 0, 5 mm.

Frame, rectangular, with two corrugated ends and two straight sides or any other appropriate

Device to check the squareness of ends with respect to corrugations, with an accuracy of 1 mm.

Procedure

Lay the sheet flat and square on the surface, ensuring that the valley of every corrugation is in contact with it. Measure the out-of-squareness at each end, as indicated in Figure 22, for example.

Compare the results, expressed in millimeters, with the specification given.

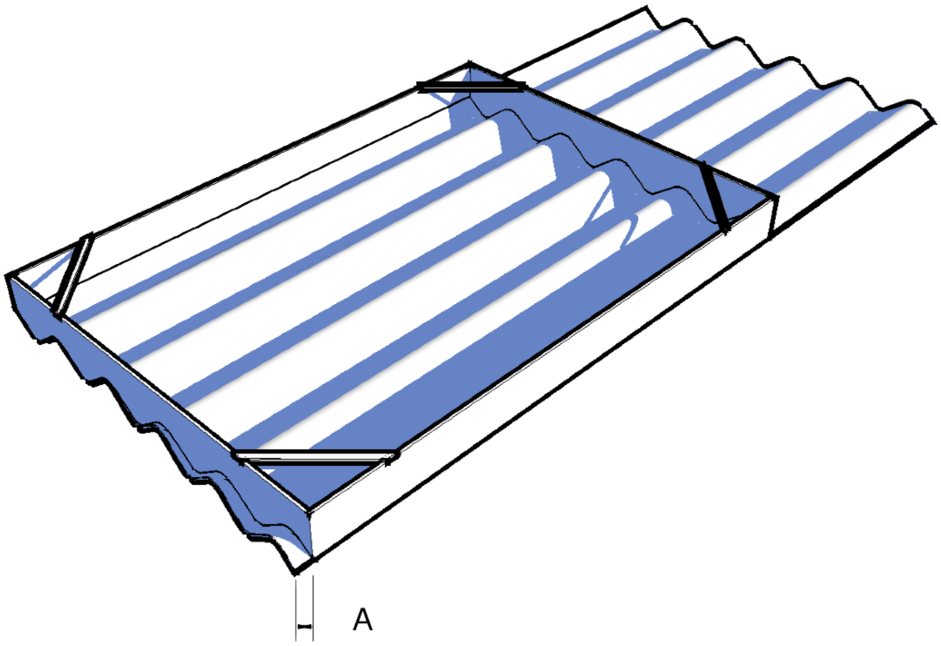


Figure 22: Measuring out of squareness

TEST RESULTS - MEASUREMENT OF OUT- OF- SQUARENESS OF SHEETS

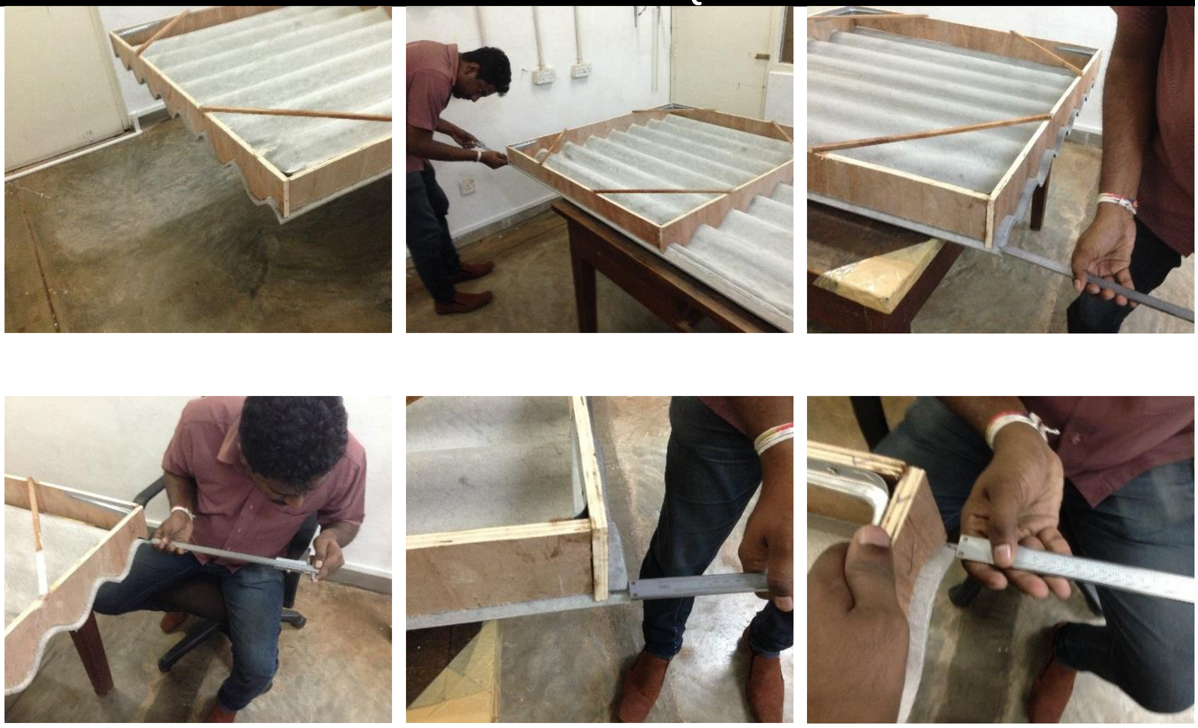


Figure 23: Recording Bending strength of flat sheets

Crystallite asbestos

Sample 1	A	11.1mm
Sample 1	A1	8.74mm
Sample 1	A2	9.87mm
Average		**9.90mm**

Fiber cement roofing sheet

Sample 1	A	17.92mm
Sample 1	A1	21.1mm
Sample 1	A2	17.46mm
Average		**18.82mm**

Measurement of the height of edges for sheets

Apparatus

- **Surface,** smooth, flat, with dimensions appropriate to the dimensions of the sheet.
- **Device,** for measuring the height, h_{om}, of the ascending corrugation.
- **Device,** for measuring the height, h_{od}, of the descending corrugation.

Procedure

Lay the sheet flat and square on the surface, ensuring that the valley of every corrugation is in contact with it. Use the measuring devices to measure, to an accuracy of .1 mm, the height of both edges, as in Figure 3. Compare the results, expressed in millimeters, at any point on the edges of the sheet with the specification.

Measurement of length and width for fittings

Apparatus

The apparatus is the same as for sheets.

Procedure

For each dimension, take two measurements (one at each end). Read each measurement to the nearest millimeter. Calculate the arithmetic average for each dimension and compare with the specification given in 5.3.6.

Measurement of thickness for fittings

Apparatus

The apparatus is the same as for sheets.

Procedure

Make the measurements

- On three crowns and three valleys on the corrugated parts, at approximately 15 mm from the edge, and on two distinct points on the flat part, at approximately 15 mm from the edge.

Calculate the average of the six measurements made on the corrugated part, and the average of the two measurements made on the flat part. Compare these two averages with the specification given in 5.3.6.

Breaking load and the bending modulus of sheets

This annex gives a method of test for measuring the breaking load and calculating the 'bending modulus of fiber-cement profiled sheets, and the procedures used for the • determination of compliance with the requirements of this International Standard.

Principle

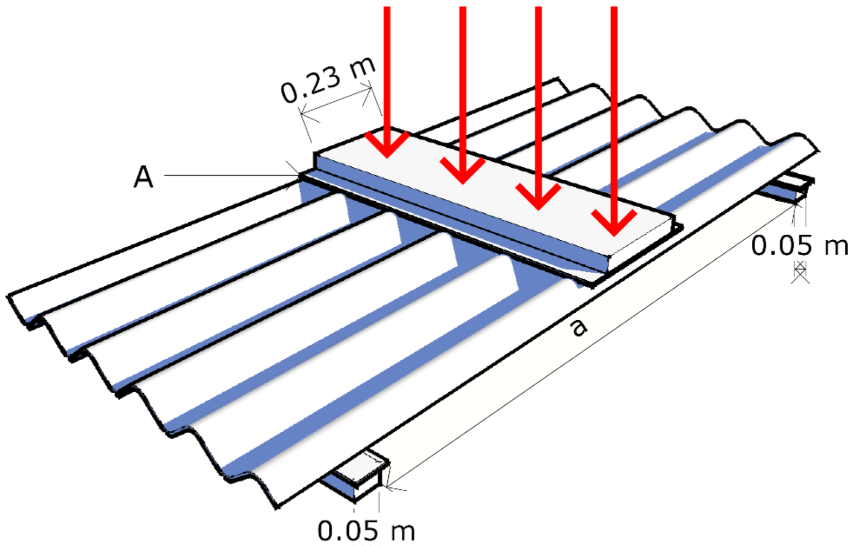
A profiled sheet or a specimen cut from a sheet is supported at two longitudinal ends and subjected at mid-span to a flexural bending load until failure occurs (three-point bending). The load/deflection relationship, as well as the **failure load, is** recorded.

Measurement of breaking load

Apparatus

- **Bending test machine,** with a constant rate of deflection when applying the load (where this facility is not available, a constant rate of loading is acceptable), with an error of accuracy and an error of repeatability less than or equal to 3 %; see
- This machine is comprised of the following:
  - two parallel supports (one fixed), set in the same horizontal plane and longer than the sample width; the upper surface of each support shall be flat and 50 mm wide; the distance between the supports shall be set to give a clear span of 1,1 m,
  - a rigid, flat loading beam, 230 mm wide, of the same length as the supports and, parallel and equidistant from them; it shall be attached to the mechanism by means of a flexible joint;
  - three strips of felt or soft material approximately 10 mm thick.

Dimensions in millimeters



Key

A strips of felt of soft material

a 15 1 100 mm.

Figure 24: Breaking load test

Procedure

For sheets having a height of corrugation greater than 80 mm, increase the span to at least 15 times the height of the corrugation.

For sheets shorter than 1,2 m, reduce the clear span to a minimum of 700 mm or 12 times the height of the corrugations, whichever is greater, and reduce the width of the loading beam by the ratio of this clear span to 1,1 m.

Place the specimen on the supports (the upper face in compression), which are at right angles to the corrugations. After interposition of strips of felt or soft material, load the specimen at mid-span using the flat beam, distributing evenly the load applied on its centre.

Measure the deflection, expressed in millimeters, at mid-span (below the loading head) to an accuracy of 0,1 mm, and plot these values against the corresponding loads. If the deflection is determined by incremental readings, use at least six pairs of readings.

The rate of loading shall be such that the rupture occurs between 10 s and 45 s after the start of its application. Record the load at rupture, i.e. maximum load, F.

Calculation of breaking load per metre of width

The breaking load per meter of width, Fs, expressed in newton per meter, is given by Equation (C.1):

$$F_s = \frac{F}{b} X 10^3$$

where

F: is the load at rupture, expressed in newton;

b: is the dimension of the specimen parallel to the supports, expressed in millimeters.

When a span length, /s, other than 1100 mm is used, the breaking load, F5, per meter width for comparison with Table 3 is as given in

Equation: $F_s = \frac{F}{b} . \frac{l_s}{1100mm} X 10^3$

where is l_s the clear span between the supports, expressed in millimeters.

The results shall be compared with the appropriate specification given in Table 3 for the breaking load.

TEST RESULTS BREAKING LOAD PER METER OF WIDTH

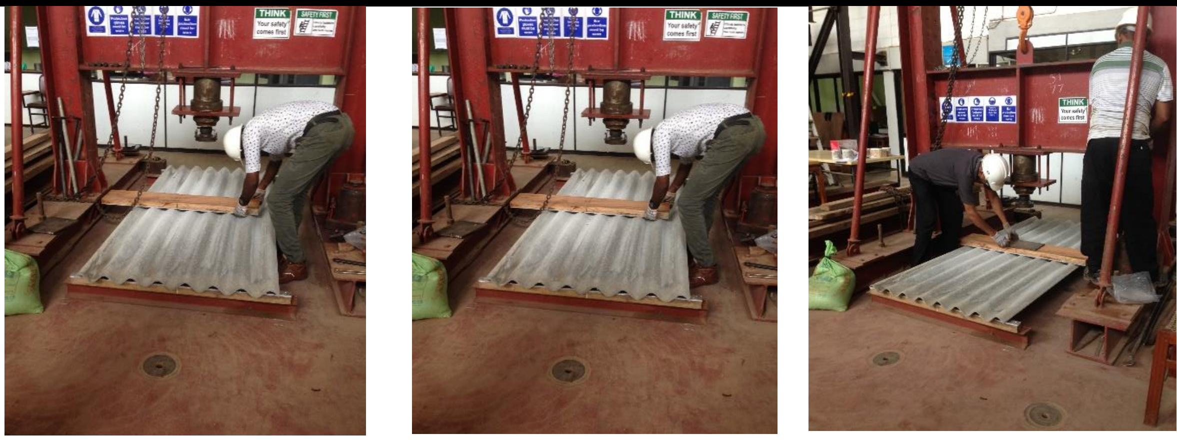


Figure 25: Recording Bending strength of flat sheets

CHRYSTALITE ASBESTOS ROOFING SHEET BRTEAKING LOAD PER METER OF WIDTH

Sample Name	F	b	l_s	Fs
Sample 1	3212N	1095	2397	**6391.72N/mm2**
Sample 2	2988N	1095	2397	**5945.95N/mm2**
Sample 3	3268N	1095	2397	**6503.16N/mm2**
Sample 4	3156N	1095	2397	**6280.28N/mm2**
Sample 5	3268N	1095	2397	**6503.16N/mm2**
Sample 6	2988N	1095	2397	**5945.95N/mm2**
Sample 7	3100N	1095	2397	**6168.83N/mm2**
Sample 8	3212N	1095	2397	**6391.72N/mm2**
Sample 9	3044N	1095	2397	**6057.39N/mm2**
Sample 10	3326N	1095	2397	**6618.58N/mm2**
Average	**3156N**	1095	2397	**6280.67N/mm2**

FIBER CEMENT ROOFING SHEET BRTEAKING LOAD PER METER OF WIDTH

Sample Name	F	b	l_s	Fs
Sample 1	1644N	940	1700	**2702.67N/mm2**
Sample 2	1784N	940	1700	**2932.84N/mm2**
Sample 3	1700N	940	1700	**2794.74N/mm2**
Sample 4	1616N	940	1700	**2656.63N/mm2**
Sample 5	1672N	940	1700	**2748.70N/mm2**
Sample 6	1700N	940	1700	**2794.74N/mm2**
Sample 7	1588N	940	1700	**2610.60N/mm2**
Sample 8	1532N	940	1700	**2518.53N/mm2**
Sample 9	1756N	940	1700	**2886.81N/mm2**
Sample 10	1616N	940	1700	**2656.63N/mm2**
Average	**3156N**	1095	**2397**	**3304.77N/mm2**

Bending modulus (modulus of elasticity)

The bending modulus, Em, expressed in newton per square millimeter, of each of the specimens is calculated as given in Equation.

$$E_m = \frac{(F_0 \quad - F_{0,15})(l_s)}{48I(f_{0,55} - f_{0,15})}$$

l_s	is the span, expressed in millimeters;
$F_0 \quad - F_{0,15}$	is the increment of load,' expressed in newton per meter, on the straight line portion of the load-deflection curve; see Figure C.2;
$f_{0,55} - f_{0,15}$	is the increment of deflection, expressed in millimeters, at the mid-span of the test specimen, corresponding to F0,55 —F0,15;
I	is the moment of inertia of the section around a horizontal axis through the center of gravity expressed in mm4;
$F_{0,15}$	shall be approximately 15 % of the maximum load;
$f_{0,55}$	shall be approximately 55 %bf the maximum load.

The bending modulus for each specimen shall be expressed to four significant figures.

The results shall be compared with the appropriate specification given in Figure 26 for the bending modulus.

0,15 [f]0,55

Key

X deflection, expressed in millimeters

Y load, expressed in newton per meter

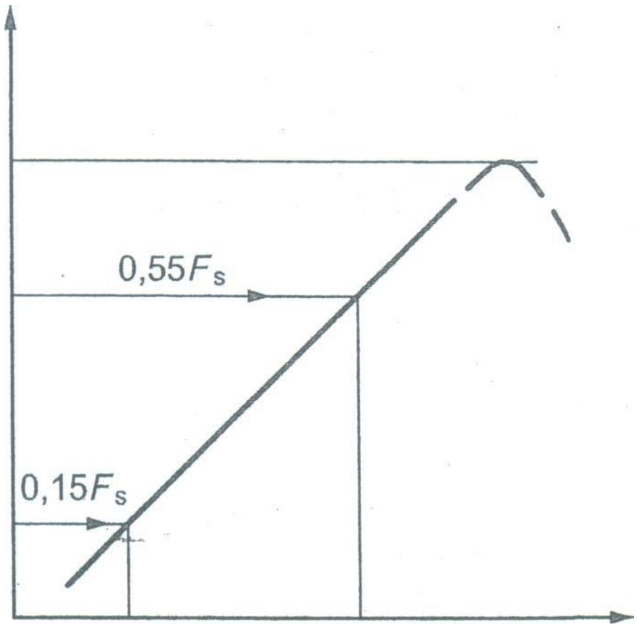
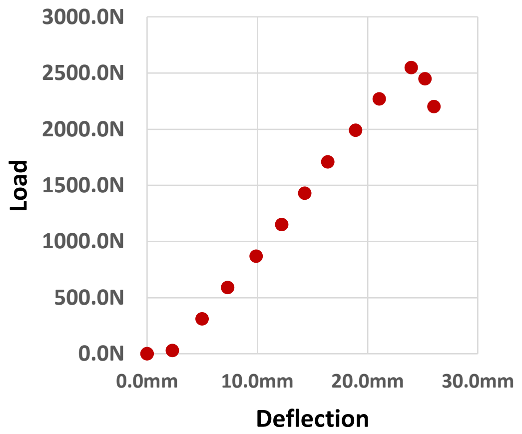


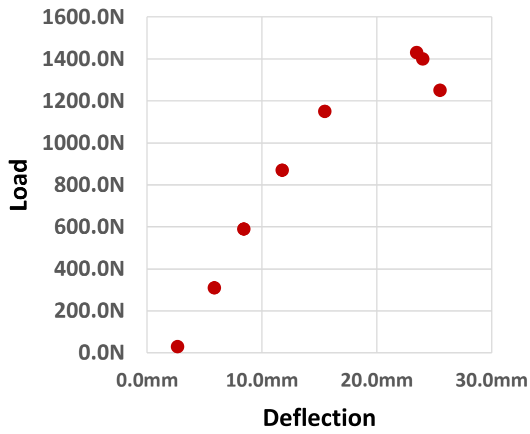
*Figure 26: **Measurement of deflection during breaking load test***

TEST RESULTS

CHRYSTALITE ASBESTOS SHEETS



CEMENT FIBER CORRUGATED SHETS



Bending moment of a sheet

General

This annex gives a method of test for measure in the bending Moment of fibre-cement profited sheets and the procedures used for the determination of compliance with the requirements of this International Standard.

Principle

A specimen cut from a profiled sheet is supported at two ends and subjected at mid-span to a flexural bending load until failure occurs (three-point bending).

Measurement of bending moment

Apparatus

- **Bending test machine,** with a constant rate of deflection when applying the load (where this facility is not available, a constant rate of loading is acceptable) and with an error of accuracy and an error of repeatability less than or equal to 3 %.

This machine is comprised of the following:

- two parallel supports (one liked), set in the same horizontal plane and longer than the sample width; the face of each support shall be rounded to a radius of 3 mm to 25 mm;
- Either a loading bar for sheets, or a rigid loading beam of suitable width for sheets, longer than the sample length, parallel to the supporting and located at the same distance of each of them; it shall be attached to the mechanism by means of a flexible joint;
- strip of felt or soft material approximately 10 mm thick, longer than the sample length and wider than the loading bar or the rigid beam. '

Procedure

Place the specimens on the supports (the upper face in compression) and, after interposition of strips of felt or soft material, load in middle at the top of corrugation, using the loading bar or the rigid beam, depending on the type.

Adjust the rate of loading such that the rupture occurs between 10 s and 30 s after the start of its application.

Record the load at rupture, F.

Calculation of bending moment per meter length

The bending moment, M, at rupture per meter length, expressed in newton-meters per meter, is given by Equation (D.1) for sheets of constant thickness [see Figure 2 a)] and by Equation (D.2) for sheets of variable thickness [see Figure 2 b)]:

$$M = \frac{F}{6} X \frac{l_s}{b}$$

where

F is the load at rupture, expressed in newton;

b is the width of the specimen, expressed in millimeters;

l_s is the span, expressed in millimeters;

TEST RESULTS BENDING MOMENT OF A SHEET

Figure 27: Recording Bending strength of flat sheets

CHRYSTALITE ASBESTOS ROOFING SHEET BENDING MOMENT

	F	b	ls	M
Sample 1	450N	400	290	54N
Sample 2	338N	400	290	41N
Sample 3	366N	400	290	44N
Sample 4	366N	400	290	44N
Sample 5	310N	400	290	37N
Sample 6	478N	400	290	58N
Sample 7	478N	400	290	58N
Sample 8	506N	400	290	61N
Sample 9	562N	400	290	68N
Sample 10	562N	400	290	68N
Average	**442N**	**400**	**290**	**53N**

FIBER CEMENT ROOFING SHEET BENDING MOMENT

	F	b	ls	M
Sample 1	114N	400	255	12N
Sample 2	86N	400	255	9N
Sample 3	114N	400	255	12N
Sample 4	86N	400	255	9N
Sample 5	114N	400	255	12N
Sample 6	86N	400	255	9N
Sample 7	114N	400	255	12N
Sample 8	86N	400	255	9N
Sample 9	86N	400	255	9N
Sample 10	86N	400	255	9N
Average	**97N**	**400**	**255**	**10N**

Determine the apparent density

General

This annex gives the test method for determination of the apparent density (see 7.3.4) of fibre-cement profiled sheets. This is the average density of the material and its pores.

Principle

The volume of a saturated specimen is determined by immersion in water. The specimen's oven-dry mass is then measured. The apparent density is determined by calculation from the measured values.

Apparatus

- Oven, ventilated, capable of achieving a temperature of 100 °C ± 5 °C with a full load of specimens.
- Balance, accurate to within 0,1 % of the specimen mass, equipped to determine both the immersed mass and the non-immersed mass of the specimen.

Test procedure

Immerse specimen in water for at least 24 h.

Take saturated specimen, remove excess water from surfaces and then determine the volume, V, of the water displaced by the saturated specimen when placed into a water bath. Record this value. Any other method having an equivalent accuracy may be used.

Remove specimen from water bath and place it into a ventilated oven that is maintained at a temperature of 100 °C 5 "C until the specimen has reached constant mass, determined as a difference between successive weighing of less than 0,1 % in any 24 h period. Record this value as m.

Calculation of apparent density

The apparent density, p, expressed in grams per cubic centimetre, is given by Equation (F.1):

(F 1)

where.

m is the mass, expressed in grams, of the test piece after drying; V is the volume of the specimen, in cubic centimeters.

TEST RESULTS – DENSITY

Figure 28: Recording Density

DENSITY CHRYSTALITE

Asbestos	Water Displacement	Dry Weight	Density
Sample 1	0.0000370m3	0.0622Kg	1681.08 Kg/m3
Sample 2	0.0000380m3	0.0610Kg	1605.26 Kg/m3
Sample 3	0.0000380m3	0.0619Kg	1628.95 Kg/m3
Sample 4	0.0000360m3	0.0597Kg	1658.33 Kg/m3
Sample 5	0.0000380m3	0.0622Kg	1636.84 Kg/m3
Sample 6	0.0000389m3	0.0612Kg	1573.26 Kg/m3
Sample 7	0.0000380m3	0.0607Kg	1597.37 Kg/m3
Sample 8	0.0000370m3	0.0620Kg	1675.68 Kg/m3
Sample 9	0.0000390m3	0.0621Kg	1592.31 Kg/m3
Sample 10	0.0000380m3	0.0629Kg	1655.26 Kg/m3
Average			**1630.43 Kg/m3**

DENSITY FIBER CEMENT

Fiber cement	Water Displacement	Dry Weight	Density
Sample 1	0.0000400m3	0.0437Kg	1091.36 Kg/m3
Sample 2	0.0000410m3	0.0437Kg	1064.74 Kg/m3
Sample 3	0.0000400m3	0.0437Kg	1091.36 Kg/m3
Sample 4	0.0000380m3	0.0437Kg	1148.80 Kg/m3
Sample 5	0.0000380m3	0.0437Kg	1148.80 Kg/m3
Sample 6	0.0000350m3	0.0437Kg	1247.27 Kg/m3
Sample 7	0.0000340m3	0.0437Kg	1283.96 Kg/m3
Sample 8	0.0000420m3	0.0437Kg	1039.39 Kg/m3
Sample 9	0.0000420m3	0.0437Kg	1039.39 Kg/m3
Sample 10	0.0000340m3	0.0437Kg	1283.96 g/cm3
Average			**1143.90 Kg/m3**

water permeability of a sheet

General

This annex gives details of the test procedure (see 7.3.5) and apparatus required to determine that fibre-cement profiled sheets comply with the water-permeability requirements of this International Standard.

Principle

A specified depth of water is applied to the upper face of a horizontally positioned specimen for a prescribed period of time. Visual examination of the test specimen determines compliance with the requirements of this International Standard.

AO.

Apparatus

- **Frame,** constructed as shown in Figure 29 Figure 29.

The width of the frame depends on the profile of the sheets and shall be, wherever possible, greater than 0,5 m. The length of the frame shall be between 0,5 m and 1,0 m.

Dimensions in millimeters.

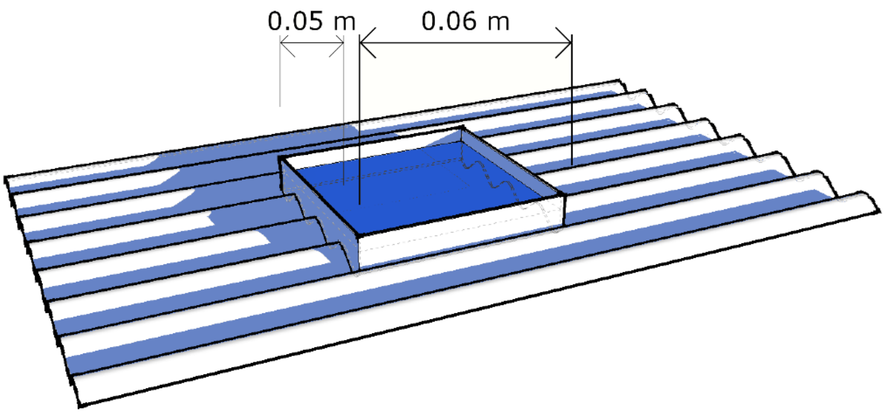


Figure 29: Arrangement for the water permeability test

Procedure

Seal the frame on the upper face of the specimen. Place the specimen horizontally, in normal laboratory conditions and above the ground, e.g. on supports, in such a way as to allow visual inspection of the under face. Without moving the specimen.

Fill the frame with water until the level is approximately 20 mm above the top of corrugations and maintain the level constant during the test.

After 24 h, examine the under face for the presence of water drops. Report the visual condition of the specimen. Compare the result with the specification given.

TEST RESULTS – WATER PERMEABILITY TEST

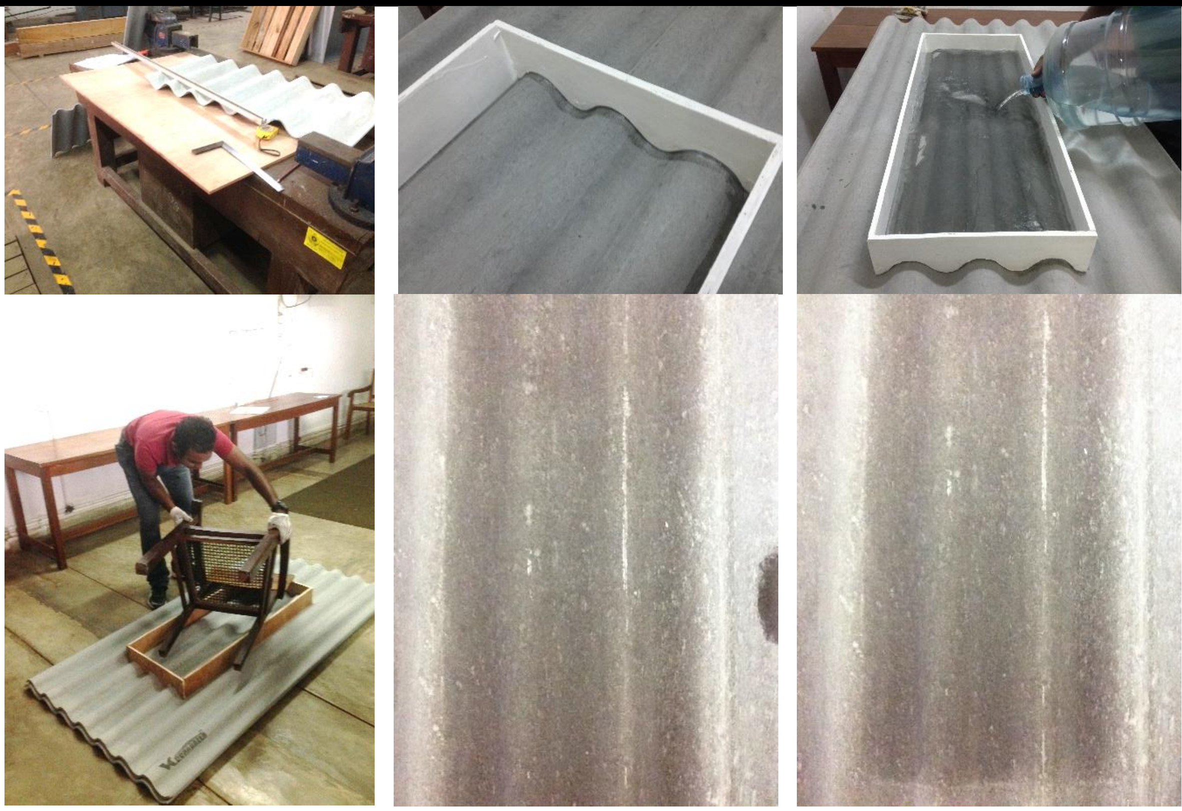


Figure 30: NAIL HEAD PULL THROUGH TEST

TEST RESULTS - NAIL HEAD PULL THROUGH TEST

Asbestos		Results
Sample 1	** No sign of water droplets after 24h of time	**Pass**
Sample 2	** No sign of water droplets after 24h of time	**Pass**
Sample 3	** No sign of water droplets after 24h of time	**Pass**
Average	** No sign of water droplets after 24h of time	**Pass**

Fiber Cement		Results
Sample 1	** No sign of water droplets after 24h of time	**Pass**
Sample 2	** No sign of water droplets after 24h of time	**Pass**
Sample 3	** No sign of water droplets after 24h of time	**Pass**
Average		**Pass**

Soak-dry performance of long and short sheets

General

This annex gives the details of the apparatus and testing procedure required to evaluate the soak-dry performance of long and short fibre-cement profiled sheets.

Principle

A lot of specimens is subjected to a number of test cycles comprising a period of immersion in water and drying in an oven. A comparison is made between the breaking load (long sheets) or the bending moment (short sheets) of the specimen exposed to soak-dry test cycling and the breaking load (long sheets) or the bending moment (short sheets) of the unexposed reference specimen from the same sample for each sample in the lot.

Apparatus

- **Oven,** ventilated, capable of maintaining a temperature of 60 °C ± 3 °C and a relative humidity less than or equal to 20 % with a full load of specimens.
- **Bath,** filled with water at ambient temperature (> 5 °C).

The water in the water bath should be saturated with soluble salts derived from fibre-cement sheets. **Test equipment,** for determination of breaking load or bending moment; see Annexes C and D.

Procedure

Divide the specimens at random into two lots of 10.

Submit the first lot of 10 specimens to the breaking load test for the long sheets (taking for w the average of two measurements of the width of the specimen) or to the bending moment test for the short sheets, including the conditioning procedure for type testing; see Table 7.

At the same time, submit ttie second lot of 10 specimens to 50 soak-dry cycles

as follows: immersion in water at ambient temperature (> 5 °C) for 18"h;'

drying in a ventilated oven at €0°C± 3°C and a relative humidity of less than 20 % for 6 h. The 20 % humidity shall be achieved for at least 3 h prior to the end of the drying period.

If necessary, an interval of up to 72 h is allowed between cycles. During this interval, store specimens in the immersed condition.

long sheets (taking for w the average of two measurements of the width of the specimen) or the bending moment test for short sheets.

Calculation of results

For each of the two lots, calculate the mean breaking load or bending moment and the standard deviation of the values obtained.

Let X1 and s1 be the mean and the standard deviation of the results obtained on the first lot, and X2 and s2 be the mean and the standard deviation of the results obtained on the second lot tested after the soak-dry cycles.

The lower estimation, L2, of the mean breaking load or bending moment after immersion in warm water (second lot) at the 95 % confidence level is calculated as given in Equation (K.1) and the upper estimation, L1, of the mean breaking load or bending moment at the 95 % confidence level of the reference (first) lot is calculated according to Equation (K.2):

L2 = X2 —(0,58Xs2) (K.1)

L1 = +(0,58 xsi) (K.2)

where the coefficient of 0,58 is related to a sampling size of 10 specimens, as defined in tS0 2602:1980, Table 1, for the unilateral level of confidence at 95 %.

Calculate the ratio, RL, as given in Equation (K.3):

RL = L2

Assess the ratio against the specification of 5.4.8.

Test report

- The test report shall contain the following information: a reference to this International Standard;
- all details necessary for complete identification of the batch of profiled sheets from which sample sheets were taken;
- dimensions of the test specimen;
- test equipment details;
- test temperature and condition of the test pieces;
- breaking loads or bending moments of exposed and unexposed sheet specimens;
- calculated results;
- date of testing.

Costing

This study has two objectives, the first to measure the impact to general public, such an impact can be calculated easily calculating the initial cost comparison of alternative roofing materials. But for dandier study the life cycle cost of alternative roofing materials was calculated.

Comparing impact of banning asbestos roofing sheets to general use in the country.

The initial cost comparison of different roofing materials could be done by using simple BOQ calculation. But different roofing materials need different roofing structures. Therefore, total house boq was prepared and roofing cost comparison was done. In order to compare the one house model was used. The model is being developed calculate the total embodied energy data and the useful life of a residential building elements, materials and equipment. The secondary objective is to simulate this house model and analyze the sustainability of different building materials. The model is being developed where the designer can then add more features to the same and understand their possible variations against the life cycle cost.

Defining a house model

The best method of selecting the house model is to use the most common house type in the country [19]. In order to find the most common house type in the country [20], the general statistics were used and analyze accordingly shown in the *Figure 31*.

Figure 31: Selected house model for the study

Statistics shows that most of Sri Lankan houses built in rural areas [21], the house model was selected from rural area. The other details such as construction materials were selected from the maximum number of building construction technology used to build houses in the country. And the data were collected from the census department.

The type of building material was selected and the maximum building type was selected into the house model developed by this research. Accordion to the most common building material for wall construction is the brick and the cement they used to build by using cement floors. The most common building material for roof is cement fiber sheets. Since the material pallet was decided, the next step is to define a house model according to the requirements of the house.

Energy accounting and LCC calculation for basic house model

Preliminary Bills of Quantities (BOQ) were calculated in order to account the amount of materials required to build the basic house model. Accession the costing was done in order to understand the cost variation of different roofing materials. Subsequently, the total energy account was transformed into the life cycle model where the total energy consumption of a period of sixty years (one life span) was calculated considering the maintenance and replacement energy cost.

LCC accounting for period of sixty years

The sixty-year life span of the affordable house was defined by using British standards. The sixty-year definition helps the research to omit unnecessary calculation. However, all the selected roofing materials have the life span more than sixty years, therefore, the replacement cost of roofing materials was neglected from the LCC calculation process. But necessary maintenance cost was included while calculating the total life-cycle cost of the building. Hence, the total life cycle cost is calculated by using following equation 1.

$$LCC = IC + (MC + EC + Oc) + Uc - Rv \qquad (1)$$

Initial Cost (IC)

The initial cost of the basic house was calculated by using Bills of Quantity sheet considering 2016 market prices. Quantities were calculated by using Taking off the sheet. Then the roofing materials changes and the quantity changes due to the differentiation in roofing material were added to BOQ.

Maintenance Cost (MC)

Maintenance cost of the building calculated only for the roofing material. Other maintenance works such as roof flooring etc. were omitted from the analysis in order to understand the cost changes due to roofing materials.

Resale value

Resale value is the trade value of a building after using for a specific period. But in this case, it is sixty years. But the problem is after sixty years the basic house cannot resale. Therefore, the reusability of materials is taken into consideration. Since this is about roofing materials, roofing materials resale value only taken into final comparison.

The resale value was measured by evaklut8ng real world market conditions. The new materials price was compared with 10-year-old same materials for sale in the market. The price comparison was evaluated into value index and used to calculate the reusability of roofing materials.

LCC techniques

There are many methods of calculating life cycle cost of a residential building. Since this research is to compare roofing material LCC equipment cost and other household expenses were neglected. But the most common LCC costing techniques were used to calculate the life cycle cost of single affordable housing unit while changing the roofing materials.

Simple payback period

Simple payback period is the time taken to return the investment to build the house. This is simple as “if the house is rented to similar use the payback period of the house”. And the inflation and interest rates and cash flow or taxation were included in the calculation.

Net present values (NPV)

The net present value is simple as the value in the present of a sum of money incurred in the future. And the all the future financial investments arise throughout the life of an investment. In this case, NPV calculated for the period of sixty years (see the equation 2).

t = Cash flow requirement

i = interest rate assumptions

Energy cost (EC)

By all mean basic houses in Sri Lanka doesn't use air conditioners to cool their houses. Therefore, the energy cost is more or less zero[34]. But in order to understand the thermal comfort factors and the cooling load incurred by differentiating roofing material, It was assumed that all four types of different roofing material used houses are using an air conditioner to cool their house. The energy cost of cooling loads was calculated by using design building software for a period of sixty years.

Industrial impact factor banning asbestos sheets

The industrial impact is simply the production increase alternatives of asbestos roofing sheet. The demand of the roofing materials is the main concern in this study. The demand of an alternative roofing materials before and after banning roofing materials shall be calculated by using statistic data.

In this study all the necessary roofing alternative future demand was calculated against the existing demand of asbestos roofing sheets.

Table 2: Comparison of industrial impact

Asbestos roofing	▶	**Clay Tile**
Asbestos roofing	▶	Zinc Calum
Asbestos roofing	▶	GI Sheets (ටකරන්)
Asbestos roofing	▶	Cement roof tiles

Environmental impact after banning asbestos roofing sheets to the country

The overall argument of this paper is that Sri Lankan is such a middle income country and yet to be developed. There are many poor families those who are still wants to develop their residential house at a minimum cost. However, the overall task is to identify the sustainability after banning asbestos roofing materials in Sri Lanka. Thus in order to understand the environmental sustainability, the embedded energy was calculated and compared. The embedded energy was calculated by using energy accounting hierarchical structure. And recent literature was used to measure and evaluate the overall all embedded energy of different roofing materials in Sri Lanka.

Initial cost comparison

The initial cost comparison is very important to understand the impact to poor communities in the country. The cost factor was calculated in to one house model selected for this study. And the one square area (10ft X 10ft) was compared as a foot print to the comparison shown in the Table 3 .

Table 3: Initial cost comparison

Asbestos	Clay Tile	Zinc Calum	GI Sheets (ටකරන්)	Cement roof tiles
Rs 10,600.50	Rs 36,961.50	Rs 22,246.50	Rs 6,721.50	Rs 38,590.50

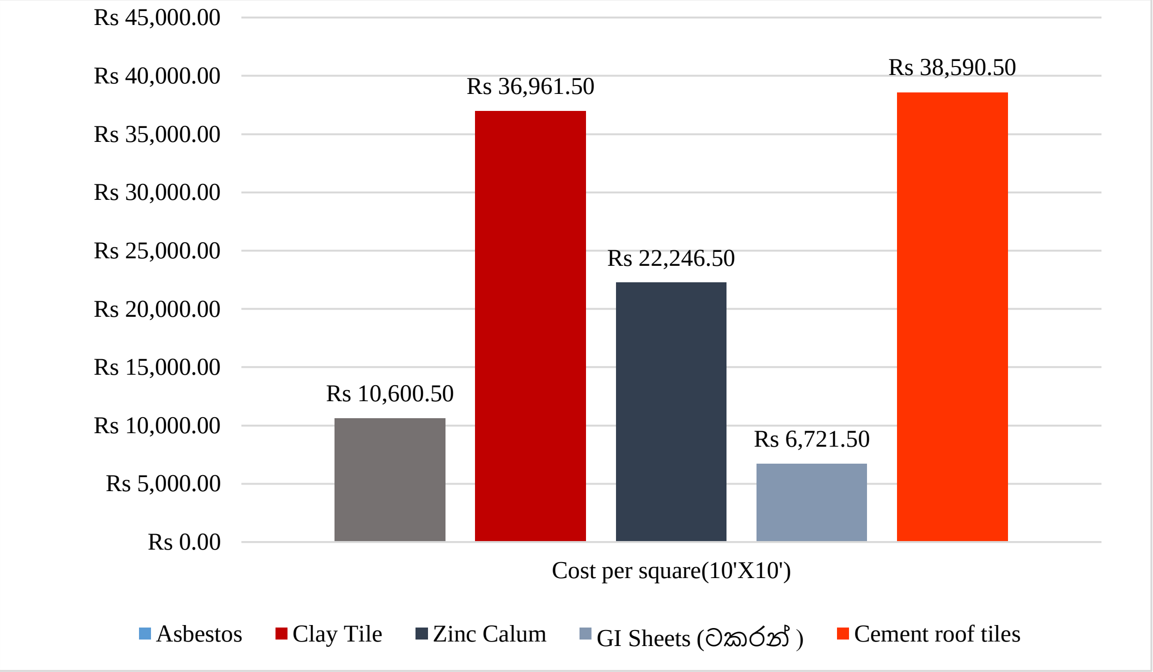


Figure 32: Initial cost comparison

Maintenance cost comparison of alternative roofing materials.

Asbestos	**Rs 4,408.50**
Clay Tile	Rs 15,373.50
Zinc Calum	Rs 19,252.50
GI Sheets (ටකරන්)	Rs 22,560.00
Cement roof tiles	Rs 16,051.50

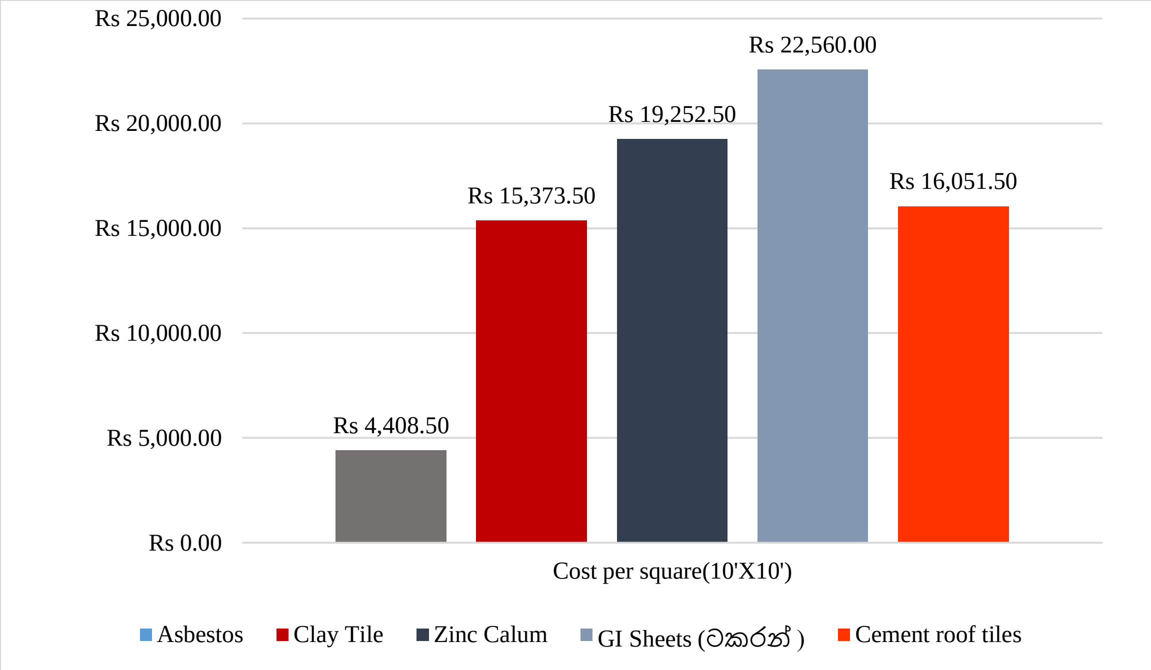


Figure 33: Maintenance cost of alternative roofing materials

Resale Values

The resale value was measured by comparing the average market price and comparing average market value of already used materials in the market. The ten year was used as a general guideline for this comparison. And then a value index (%) was given accordingly.

Table 4: Resale values of roofing materials after ten years			
Asbestos	Rs 649.50	Rs 331.50	51%
Clay Tile	Rs 120.00	Rs 33.00	27%
Zinc Calum	Rs 2,400.00	Rs 1,056.00	44%
GI Sheets (ටකරන්)	Rs 400.50	Rs 19.50	5%
Cement roof tiles	Rs 259.50	Rs 57.00	22%

Resale value is a good indicator or materials sustainability for a country like Sri Lanka. And also which shows the durability of these walling materials shown in the Table 4 . The durability was measured by conducting series of standards testing to measure the durability of these roofing materials in tropical climatic condition like Sri Lanka. And the study results were presented in a different paper.

Total life cycle cost.

The total life cycle cost was calculated by using the equation 1. The total life cycle cost includes the initial cost maintenance cost resale value and the running cost due to introduction of insulator or use of an air conditioner.

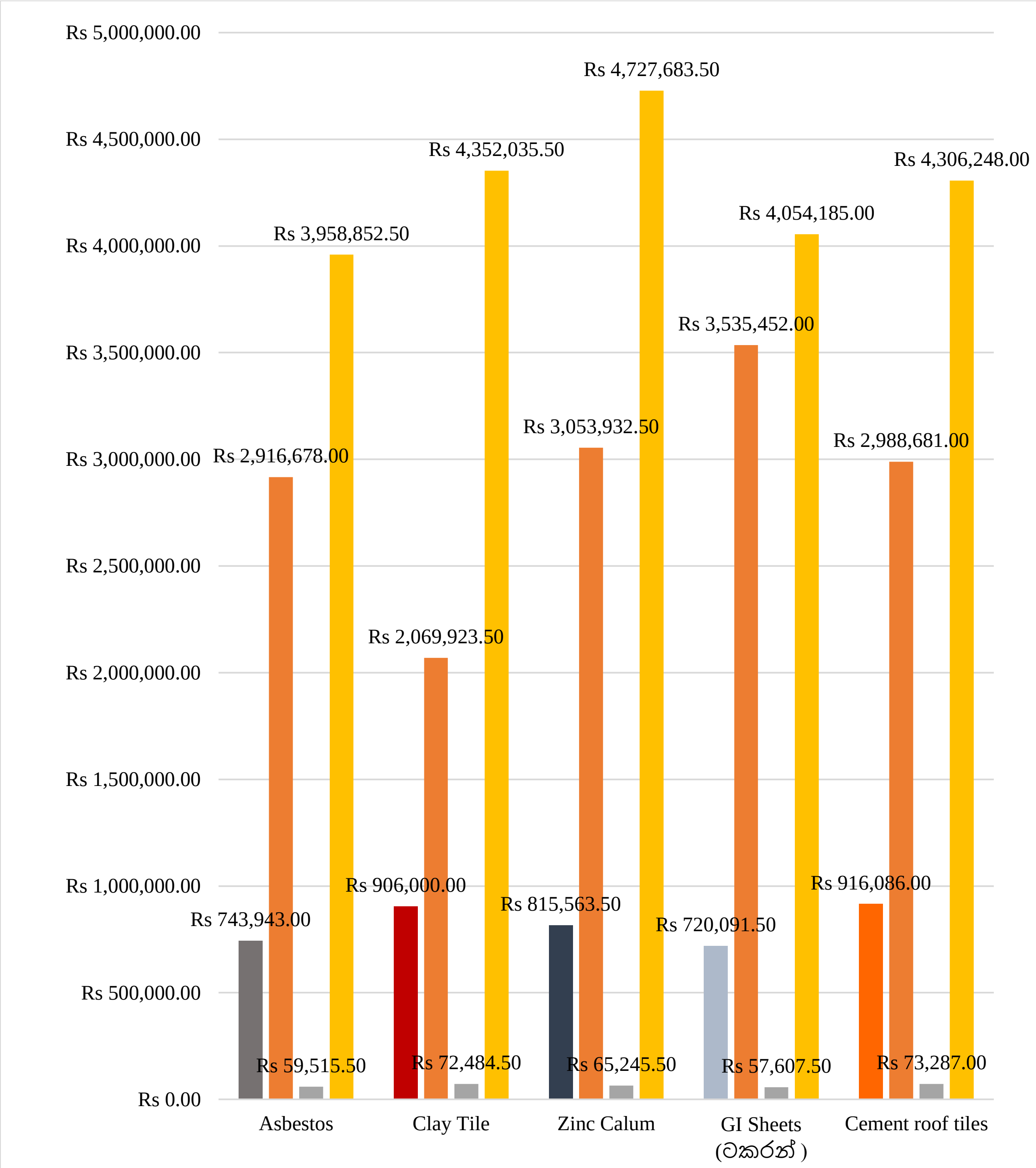


Figure 34: Total Life cycle cost of different roofing materials

Industrial Impact after banning asbestos roofing materials in Sri Lanka.

Sri Lanka is a middle income country and not having much enough resources to increase the production at a given small period of time. The production capacity cannot have increased without prior capital gain. And also there many repercussion dues to the increase of materials production in the country. The industrial impact after banning asbestos roofing materials was measured accounting other alternative roofing materials in the industry such as clay tile zinc calum GI sheets and cement roofing tiles.

Clay Tile as an alternative to asbestos sheets

Clay tile is the most common roofing material in Sri Lanka and its applications are varying from one district to another. However, if in case of banning asbestos roofing sheets clay stiles would be the best alternative considering the its spectrum of alternativeness.

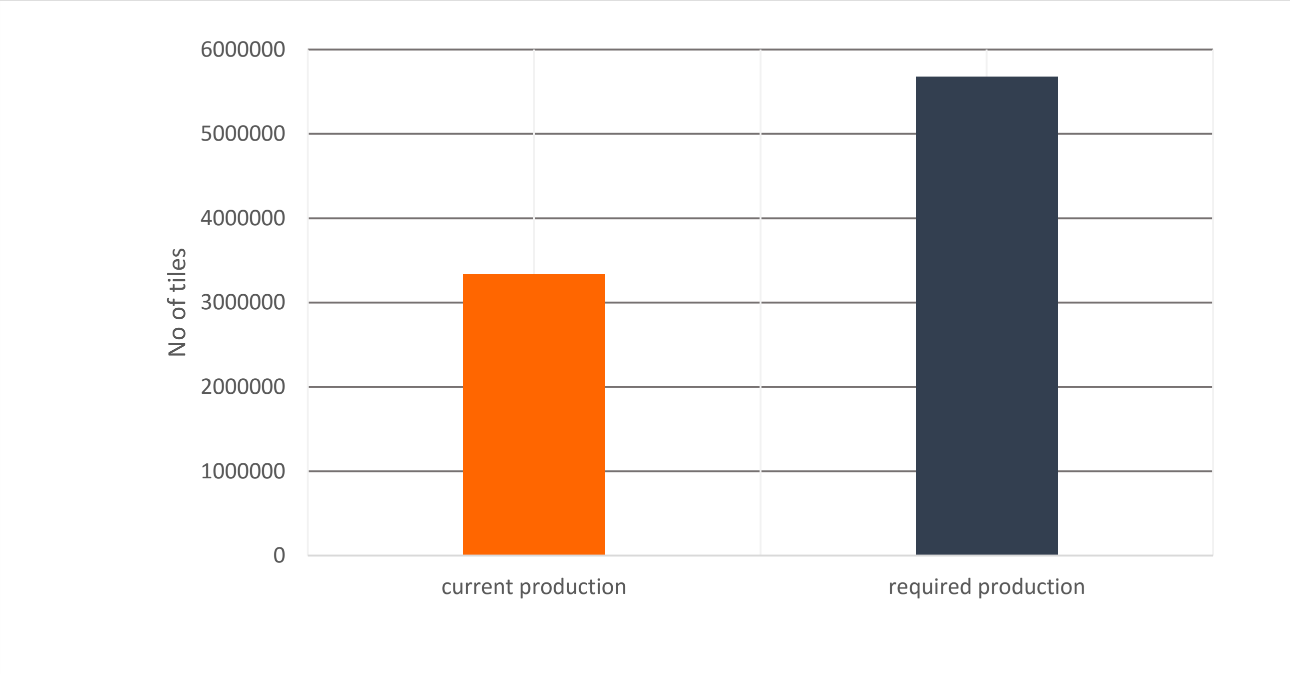


Figure 35: Required tile production to alter asbestos roofing demand after 2024

According to details of Department of senses and statistics 48.5% of total constructions has used clay roof tile as their roof covering material while 34% used asbestos. So if we want to use clay tile as an alternative there should be rapid increment of production shown in the *Figure 35*.

Price variation of Calicut tile

Table 5: Price variation on Calicut tile

YEAR	PRICE (Rs)
2014	25
2015	30
2015 before August	30
2015 August	55
2017	45

- Note- these are the selling prices of tile manufacture. End user has to pay more than that

Hence according to above values there will be several related problems related with clay tile industry when actions taken to increase the production.

- Limited availability of good quality raw material

Clay roof tile is made by red clay excavated in natural sources. Clay is the most important raw-material involved in the manufacture of tiles. Therefore, the availability and extraction possibilities play a major role in successful running of this industry. The availability of clay has been diminishing day-by-day for a long time now and the industry, at least in some parts of the country, is finding it difficult to procure the right clay. So it is very difficult task to increase the production because clay sources are not renewable sources.

Clay roof tile production cannot be continued for long period because of limited clay amount we have. So if production is increased the clay tile industry won't survive for next decade.

Increasing the clay roof tile production may reduce the clay brick production because both products depend on same raw material.

Table 6: Price variation of Clay

YEAR	PRICE (Rs)
2016	3000
2017	7000

Lack of availability of Firewood

In the industry most producer use wood as fuel to tile burning. Mostly rubber wood is used as firewood in the clay tile production. But cost of firewood is increasing rapidly and also scarcity of the wood.

Also that burning process is conducting by using much undeveloped burners. So large amount of toxic gases like (CO_2, CO) has being emitted to the environment. So there should be precautions that have to introduce before increase the production.

When increase the production price of firewood will be increased so it may have bad impacts on the other industries which also used firewood as fuel. Also high demand cause to increase the deforestation.

There are some alternatives such as coal, cashew shell and saw-dust, which can be used as fuel. So after proper research that type of alternatives should be introduced to the industry. We can't use electricity because if high cost.

Scarcity of skilled labor force

Another basic problem in the industry is the non-availability of sufficient workers to do labour intensive operations such as carrying the clay, carrying the raw-tiles for drying, setting the tiles in the kiln , taking the fired tiles out of the kiln and so forth.

So if clay roof tile is suggested as the alternative for asbestos then it has to double the production mean we have to double the workforce. Other than that required manpower can be reduced by introducing new technologies and machines to the industry.

Problem related with clay mining

Clay mining for brick and tile production usually creates clay pits or borrows areas, which, if improperly managed, can become safety hazards for employees and people live in surrounding area.

Clay pits may also accumulate rainwater and become habitat for mosquitoes. This is very dangerous because currently Sri Lanka heavily affected by deceases spread through mosquitoes.

The clay is mined mainly from paddy fields and sometimes from the banks of rivers & lakes. These processes will led to pollute the water sources and also there will be negative impacts on agricultural industry because paddy fields cannot use for cultivate after clay mining.

Dust and chemical pollution

Dust, a byproduct of brick and tile production, may cause serious health problems in workers and owners. Inhaling rock dust can lead to silicosis, a disease that affects lungs and breathing, and can eventually lead to death.

In the case of production increasing number of effected people will rise and it will give negative impacts on the industry.

Technical impacts

Clay tile cannot accommodate on large span roofs because it need bulk supportive structure with compared asbestos roofing sheets.

This will restrict the designing of large span roofs and it will lead to reduce the capabilities of the industry.

Tile roofs need more complicated and costly supportive structure and tile laying is time consuming task when comparing asbestos sheets so cost and time consuming will be more. This will make bad impact on the efficiency in construction industry.

Impacts on user

Cost per unit area of the roof will be higher when using clay roof tile, Maximum angle and shape are limited when using clay roof tile so some of the roof designed will no longer able to use

Steel cannot be used as supporting structure because of requirement complicated structure (steel usage may not cost effective because there are lots of small elements such as reefers). So effective life time of the roof may reduce unless use good quality timber.

Metal roofing Sheet as an alternative

When considering metal roofing sheet as an alternative for the asbestos sheets there are several advantages users can get by using them.

*Figure 36: GI roofing sheet used house model by National housing authority*The Sri Lankan national housing authority has lead a 65,000 housing programme with GI roofing sheets thinking it's a good alternative for asbestos. However, there are pros and cons of altering asbestos with GI sheets.

- Metal roofing can be considered as green material in the roofing industry, because it uses the least amount of resources during the manufacturing process, contains no petroleum by-products.
- Metal roofing sheets are 100% recyclable at the end of their service lives
- Generally metal roofs require none or minimal maintenance.
- Metal can withstand impact from falling objects such as hail, sticks, etc. without any damage to the roof.
- A metal roof has a cool reflective surface, which reflects solar heat back into the atmosphere, so heat inside the building will be reduced.
- Cost for supportive structure can be reduced.

But according to statics of CENSUS only 10% of currently constructed buildings have used metal sheets as their roof covering material. But to saturate the industry requirement the metal sheet production have increase around 400% because currently 34% of roof covering is built by asbestos sheets which is going to be banned.

GI sheets as alternatives for asbestos roofing sheets.

This study is focused on practical applications in the real world conditions. However, considering Sri Lankan tropical harsh climate we cannot alter the use of asbestos with GI sheets. Because there are many issues with altering asbestos with GI corrugated sheets.

1. Low strength of GI sheets.
2. Lower the life span
3. Not enough durability as a roofing materials.
4. High heat conduction.

Figure 37: Testing different roofing materials strength and durability

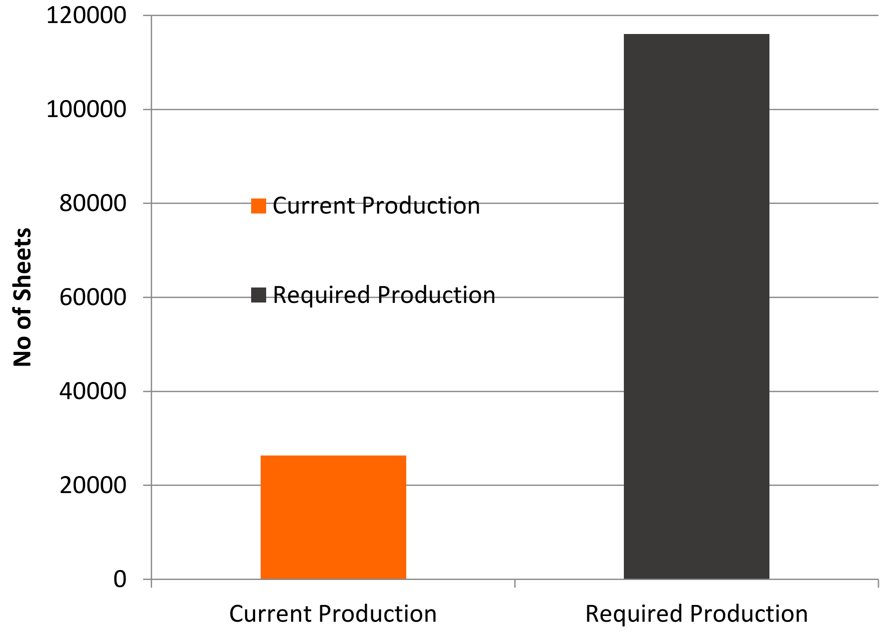


Figure 38; the impact of altering Asbestos with Zinc Calum roofing sheets

Cement tiles as alternative for asbestos sheets.

Cement roofing tiles were trending roofing materials in Sri Lanka see the figure 12. Many construction firms were booming after the news of banning asbestos roofing materials. However, cement roofing tiles are closely following the clay tiles. But yet they are heavy in term of its practical applications and the roof need extra structure to alter asbestos roof into cement roof tile roof.

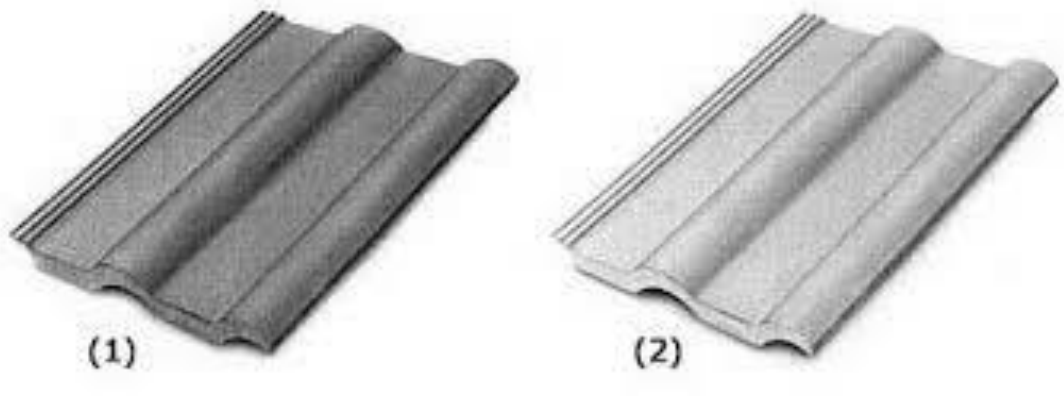


Figure 39: Cement roofing tile.

Although cement roof tile production is practical in some sense, they already many practical issues. Most early concrete roof tiles had durability problems, especially in areas with frequent rain water cycles, most concrete roofing tile fails and break.

And also cement roofing tile is not suitable for areas with monkeys. They are not strong enough to carry extra weight.

But there are strong cement roofing tiles and they very expensive in the Sri Lankan Market. Not only expensive cement roofing tiles have heavy embodied energy due to use of cement as main stabilizer for the production of cement based roofing tiles.

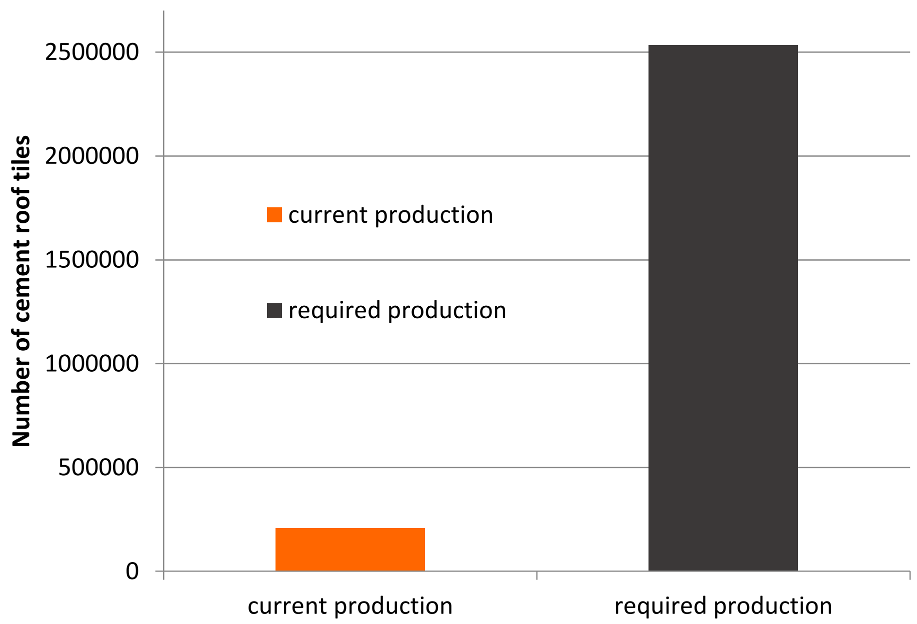


Figure 40: Number of cement tiles required to alter asbestos roofing vacuum.

Environmental impact after banning Asbestos roofing sheets in Sri Lanka.

The embodied energy of different roofing materials is a good indicator of environmental sustainability of a construction material. But in this case first calculated the initial embodied energy of different roofing materials used to building one house model explains in the methodology section.

Initially embodied energy of roofing materials was calculated per single unit. The modular of one roof material was calculated into the roofing embodied energy. This is to understand the unit embodied energy. But this is not enough to do a comparison. Hence embodied energy per single square (10ft X 10ft) was calculated for an affordable house used to be built in Sri Lanka.

Table 7: Modular unit embodied energy of alternative roofing materials

Asbestos	**Clay Tile**	**Zinc Calum**	**GI Sheets (ටකරන්)**	**Cement roof tiles**
256.0 MJ	23.0 MJ	1080.0 MJ	980.0 MJ	198.5 MJ

Embodied energy comparison of alternative roofing materials

The embodied energy was calculated by using energy counting hierarchical structure. And then the modular embodied energy was measured for square area by using real world house model which has been built all-round the country see the methodology section 0.

Table 8: embodied energy of alternative roofing materials per one square.

Asbestos	Clay Tile	Zinc Calum	GI Sheets (ටකරන්)	Cement roof tiles
999.2 MJ	4457.3 MJ	7726.8 MJ	7011.4 MJ	18070.2 MJ

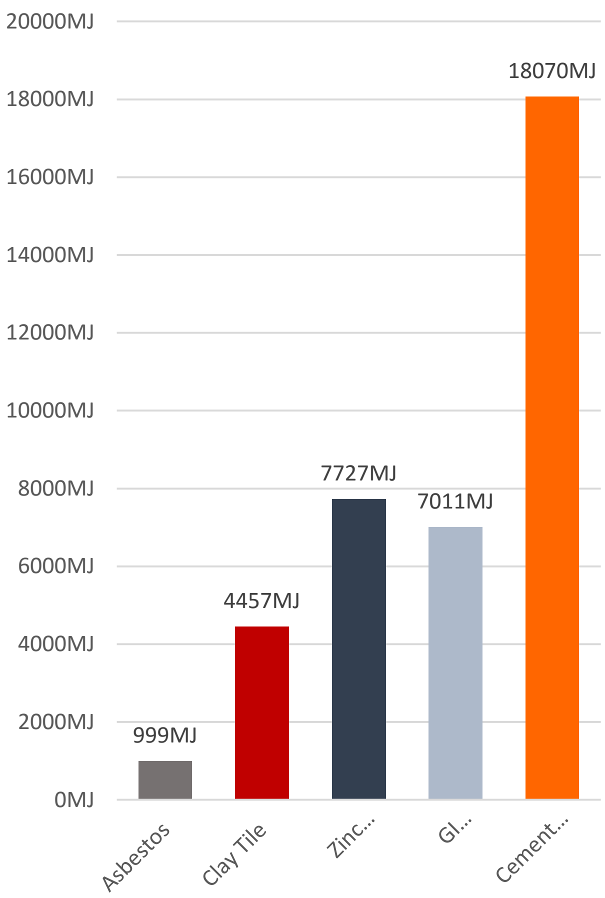


Figure 41: Embodied energy per one square (10ft X 10ft)

Reusability index of alternative roofing materials.

Reusability index is a good indicator of environmental sustainability, because reusable materials helped to reduce the environmental degradation reducing raw materials consumption to manufacture these roofing materials. The reusable index was prepared by using the resale value. In most cases there are no 100% reusable roofing materials in the country after period of ten years. The ten year definition was taken as a margin for the calculations to understand the value reduction shown in the Table 9.

Table 9: Reusability index of roofing materials

Roofing Material	Reusability Index
Asbestos	0.51
Clay Tile	0.27
Zinc Calum	0.44
GI Sheets (ටකරන්)	0.05

Cement roof tiles	0.22

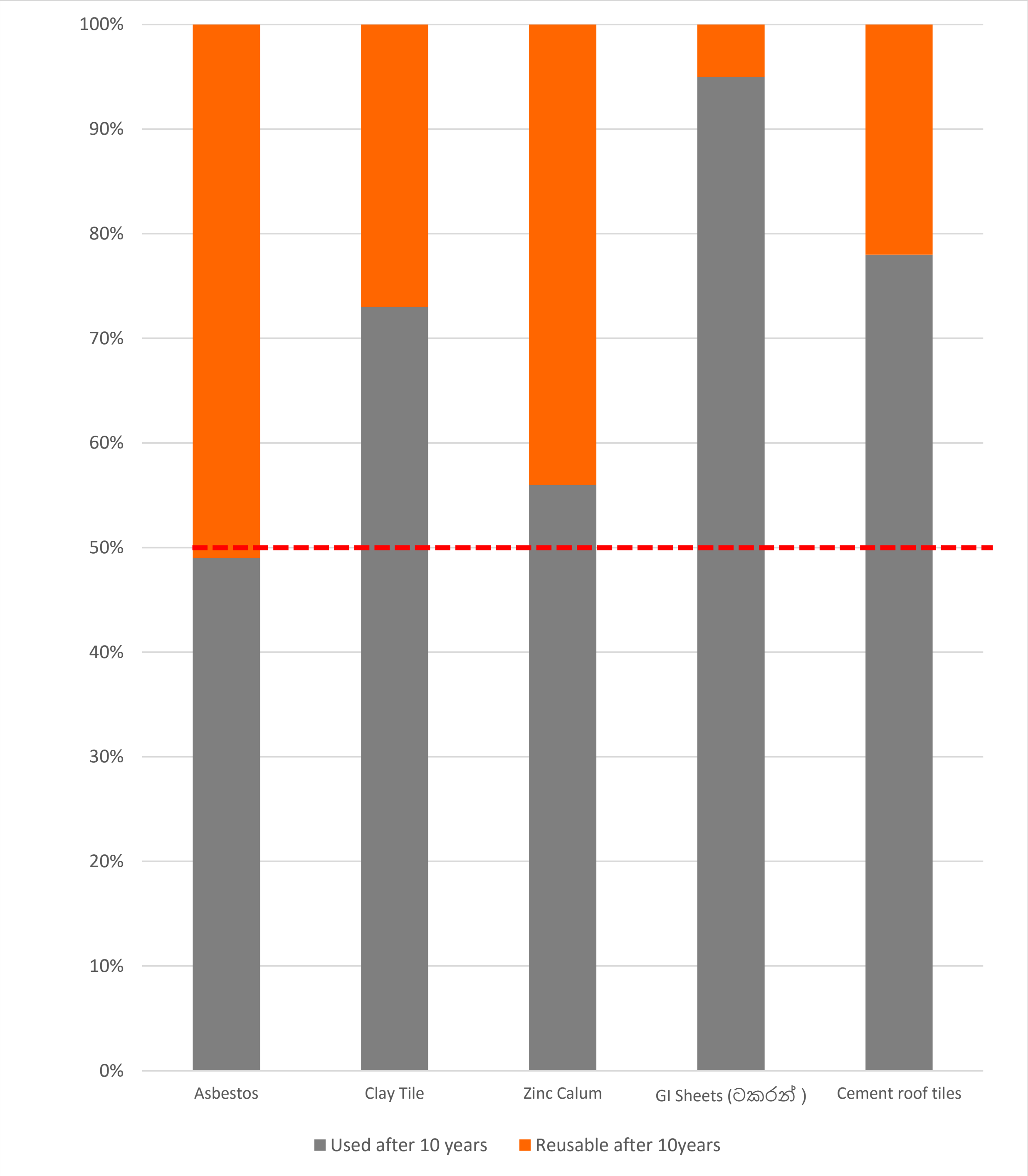


Figure 42: Reusability of alternative roofing materials

The *Figure 42Figure 42: Reusability of alternative roofing materials* shows reusability of roofing materials comparing to the asbestos roofing sheets. Most of the roofing materials are not even 50% reusable after ten years of time. Even if they are reusable, unlike asbestos roofing sheets which would be really difficult to reuse from one roof to another without proper mechanism of changing the roofing tile.

Discussion

Asbestos in loose form is dangerous. In Sri Lanka, loose form has not been used in our production so the main reasons for this whole issue are misconception of the name asbestos, and the way it has been misused. Coordinator of the Fiber Cement Product Manufacturers Association (FCPMA) of Sri Lanka, Anton Edema spoke to The media and refuted the allegations made with regard to the use of asbestos in the country and said no one has ever been able to prove that it was hazardous. Concurring to them "Not a single death has been reported for the past 70 years by having asbestos roofing. All what they do is quoting outdated information from the internet and say it has caused this much of deaths. But it has not yet been proved by anyone that in Sri Lanka anyone has died of having asbestos roofing,"

According to FCPMA, without any consistent evidence banning asbestos is meaningless and we are subjected to this type of situation due to the trade war between the EU and Russia. And the discussion should be **"Are we strong enough to ban asbestos as a roofing materials?"**

The initial cost estimate as well as the life cycle cost estimation shown in the Figure 34 explains that asbestos is the most suitable roofing materials for Sri Lanka and other alternative yet to be considered as expensive for a middle income country like Sri Lanka.

Economical sustainability

The priority for a middle income country like Sri Lanka is to reduce the cost and develop its infrastructure. Thence the first priority should be to improve the cost. However, cost wise alternative for asbestos are not great in terms of their initial cost maintenance cost and resale value. Asbestos are the best roofing materials in terms of overall. The GI sheets are very cost effective but need to be replaced from time to time. And GI sheets resale value is almost close to Zero. And the so called alternative of clay tiles are highly expensive comparing to the other roofing materials in the list *Figure 33*.The industry wise it would greater problem to alter the demand of asbestos roofing sheets I the country. The results sows that clay tile manufacturing increase should be more than 400% and need many infrastructure developments. And yet increasing clay tile production would be environmental hazardous process. The zinc Calum is good alternative, since it's an imported roofing materials. But there is a limit to import for a middle-income country like Sri Lanka. However, cement roofing tiles can be increased the manufacturing but its carbon footprint is very high comparing to other roofing materials in the industry.

Environmental sustainability

Environmental conservation should be a priority for an eco-friendly country like Sri Lanka. By banning asbestos can save the country natural beauty by introducing good alternatives. But the study shows that already existing alternatives are not environmentally sustainable comparing asbestos.

The asbestos roofing sheet area of one square account for 999MJ while others are way above asbestos embedded energy. Cement tile roof accounts for highest embodied energy dues its use of cement and machinery during manufacturing process. Clay tile is the next best product but it's consume most of fire wood to manufacture the clay tiles. The steel products have much bigger energy foot print because of their manufacturing methods. However, asbestos roofing sheets are nest in that sense except its health hazards.

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