Volume 1 Issue 1

# International Journal of Advances in Science Engineering and Technology

# IJASEAT

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THE IJASEAT JOURNAL

International Journal of Advances in Science, Engineering and Technology(IJASEAT)





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## Volume-4,Issue-1 ( Jan, 2016 )

Total Viewed 2077

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### Part 1

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## Editorial Board

# SOUND TRANSMISSION CLASS (STC) OF FIXED WINDOW GLAZING IN WARM HUMID ENVIRONMENT

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**Abstract-** Acoustic property of glass material for window in term of sound transmission class (STC) within a warm humid environment of Indonesia is studied. Earlier research, books, and glass manufacturer's manual informs STCs of glass material. Nevertheless, the use of glass in buildings in warm humid air may cause a decrease or increase in STC. The fluctuation of STC is estimated to be affected by warmer air. In the case of developing country such as Indonesia, limited knowledge and awareness of Indonesians may also play a role in different installation techniques and supporting materials used that may create variation in STCs compared to the manual or standard. A series of laboratory test was conducted to see STCs of Indonesian glass in a conditioned temperature higher than is outlined by ASTM. The relative humidity was also set to represent relative humidity of Indonesia. Composite wall testing method by ASTM E90-09 was employed for fixed window glass. The tests informs that STC of Indonesia glass slightly lower to that of UK glass, i.e. Pilkington. Variety in glass types (transparent ordinary float/flat glass, laminated, tempered, and frosted glass) did not produce significant STCs variation, which is 1-2 only. Higher room temperature of 31-32 C also produced no significant STCs, which is 1 only. This may become a new reference that temperature variation in test room do not play significant role as long as the temperature has no impact on molecular deformation of the test specimen. It is concluded that the most decisive factor of glass material used for fixed window system is density, which for these test specimens remain in approximately 25 kg/m2. Further investigation on molecular formation of glass material and study on open window glass is recommended.

**Keywords-** glass window, sound transmission class, warm humid environment

## I. INTRODUCTION

The use of glass windows to replace conventional wall materials, usually degrades sound insulation property of the wall. This caused by thinner dimension of the glazing materials. Since the use of glass is now becoming a trend, buildings that use glass have potentialities to suffer from environmental noise. Glass installation techniques may result different sound transmission class (STC) to that given by the glass manual handbook. Improper glass installation and the use of improper supporting material, such as frame and sealing materials, will easily decreases STC. As for sound transmission, even a tiny leak plays a role on insulation loss. As a rapid developing country, the use of glass for modern buildings is also a trend in Indonesia. Unfortunately, if builders do not care to proper installation and supporting material, the window glass may only provide very limited sound insulation from environmental noise. Loose acoustic regulation, limited knowledge and awareness of Indonesians have caused glass window installation to meet indoor noise standard is not a critical issue [1]. Many studies on acoustical property of glass have been conducted in cities and countries with different climate to that of Indonesia. Thus, cannot be fully adopted. Even standard for conducting acoustical testing of partitions, including glass partitions was set to comply room temperature in the range of 22 ± 5°C (ASTM [2]), which rarely happens in Indonesia. By ASTM the average relative humidity was set be at least 30 %. This fits to Indonesia relative humidity. Even if molecular formation of glass will only respond to temperature above 600 C [3,4], a testing condition close to Indonesia climate is considered important to see whether climatic gaps between standard and on site affects sound transmission. In the last ten years, many Indonesian cities have average annual temperature of 28 C and relative humidity of 70-90%, as is Jakarta the capital city [5,6,7]. The maximum temperature might reach up to 33 C [5]. This has been seriously increased lately due to severe climatic changes in all parts of the world. Window glazing in Indonesia building mostly uses local Indonesian glass. Others, which designed by overseas architects installs imported glass, but this are very limited. There are 3 main glass manufactures in Indonesia; Asahi (the oldest and the largest), Mulia, and Tossa (the youngest). Asahi glass dominates the use of glass in Indonesia; it produces not merely flat-architectural glass for building purposes but also automotive glass. Mulia produces glass for building, containers and automotive and Tossa focuses on flat glass for building and containers. Apart from these 3 main industries, there are over 30 smaller industries that produce advanced flat glass such as laminated, tempered, frosted, etc. Magiglass is the largest here. Imported glass within limited use in Indonesia is Pilkington glass, distributed by Bali Crafindo Permai.

As a comparison, before go into laboratory test, raw materials of local glass that mainly be tested (Asahi) and Pilkington Glass (as a reference) was compiled as is Table.1. Many standards were set for glass product physical properties, but none are for raw material component and composition. Standards have set glass product physical properties such as blemish (scratches, rubs, digs, crush, knots, dirt, stones, and gaseous inclusions), chip, and crush, etc. [8]. Local standard of Indonesia (SNI- Indonesia National Standard) [9] has also not determined aspect of component and composition. It only deals with density (2450 – 2550 kg/m2 ), hardness (6-7 Moh's scale), modulus elasticity, etc. Thus, glass manufactures set their own "recipe" to comply with those physical standards. Nevertheless, the main components are always: sand, dolomite, soda and alumina oxide, as is Table 1.

**Table 1. Glass raw materials and composition**

| Raw Material | Asahi (Indonesia)[10] | Pilkington (UK, as a reference)[11] |
|---|---|---|
| Sand $SiO_2$ | 70-74% | 72% |
| Dolomite $MgCa(CO_3)$ | 6-16% | 11% |
| Soda $Na_2O$ | 12-16% | 14% |
| Alumina Oxide ($Al_2O_3$) | 0-2% | 1% |
| Potassium Oxide ($K_2O$) | No data available | 1% |
| Cullet | No data available | 1% |

By careful inspection of Table 1, we see that manufacturers may have different composition of raw materials in forming float/flat glass. Nevertheless, both Asahi and Pilkington fit physical standard of density, hardness, modulus elasticity, etc. [8,9,10,11].

## II. RESEARCH OBJECTIVES

The aim of the research reported here is to study acoustic property of float/flat glass; also called monolithic glass; utilized for window in Indonesia, especially due to glass sound transmission class (STC). The study is made specific to climatic condition of warm humid of Indonesia. This study may also be a reference for other regions with similar climatic condition and social value, i.e. loose noise regulation and people's limited knowledge and awareness on noise problem. At this stage, we report STC of glazing installation for fixed window, in order to investigate its original STC. Later stage is to study some variations of open window design commonly applied in Indonesia. This is considered more important since open window is an obligation for natural ventilation in warm humid climate, but will significantly lower the insulation property [1]. When necessary, a study on molecular formation of glass material is also planned to support STC tests.

## III. METHODS

Testing method conforms to ASTM E90-09 is employed in this research. A specific condition was taken according to Annex.3 regarding the use of composite wall system. This is due to intact glass sample that could not be inserted into the tasting room's door. The standard requires minimum tall dimension of 2.4 m, whereas the laboratory's door is limited to 2.1 m tall. For other specimens, such as brick, gypsum, etc., it is possible to construct intact partitions part by part within the testing room where proper joint between specimens or panels will not significantly affect the STC. However, this is not the case for glass, since glass sheet connectors such as sealant usually be applied thick enough, which may cause significant deviation in the testing process, and thus affects transmission loss value [12]. In using composite wall systems, filler wall with STC of roughly 15 above the predicted STC of the specimen should be employed. In this case light bricks plastered both sides with total thickness of 252 mm was used (Fig.1,2,3). The filler wall was tested prior to specimen installation, and provides an STC of 48. As a reference, 10 mm float/flat glass of Pilkington provides STC 33 [11,13]. Earlier studies significantly proven that thickness and dimension play important roles in the decrease or increase of STC, where thicker glass owns higher STC than thinner ones and larger glass dimension decreases STC than smaller ones. Thus, thickness and dimension were set as fixed variables here. Dimension of 10 mm thickness and 110 mm x 100 mm was used as glass specimen. Specimen variables are flat/float (of Asahi), laminated (of Asahi), tempered (of Asahi), frosted glass (of Asahi) and flat/float (of Mulia). Conforming to the standard, equipment used for testing is Bruel & Kjaer 2- channel building acoustic system consisting of power amplifier type 2734 and 4292 omnidirectional loud speaker as sound source, 2 pieces of type 4189 omnidirectional microphone as sound sensor, and 2-channel hand held analyzer type 2270 as the main instrument data processor. The microphones were calibrated using type 4231 prior to testing stage.

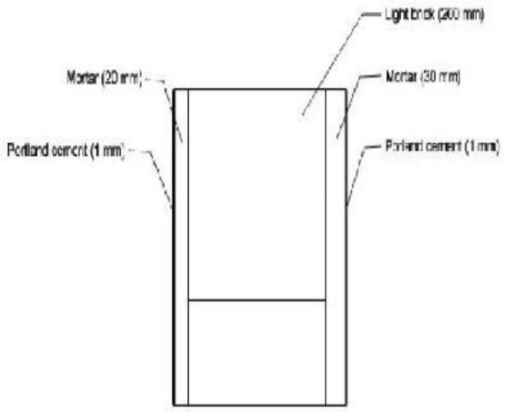


**Fig.1. Filler wall composition**

**Fig.2. Filler wall and its construction**

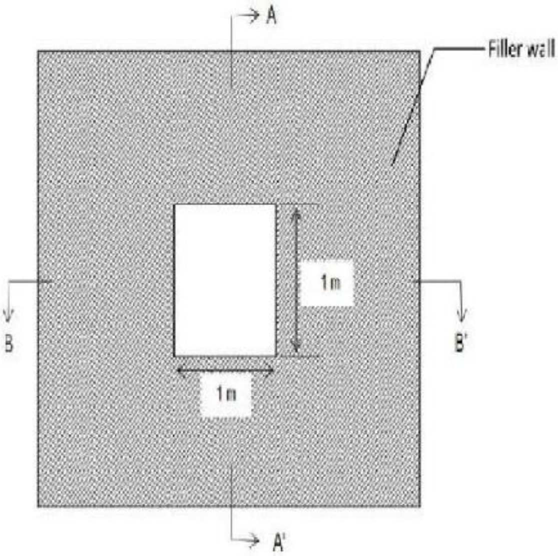


**Fig.3a. Front view of composite wall model**

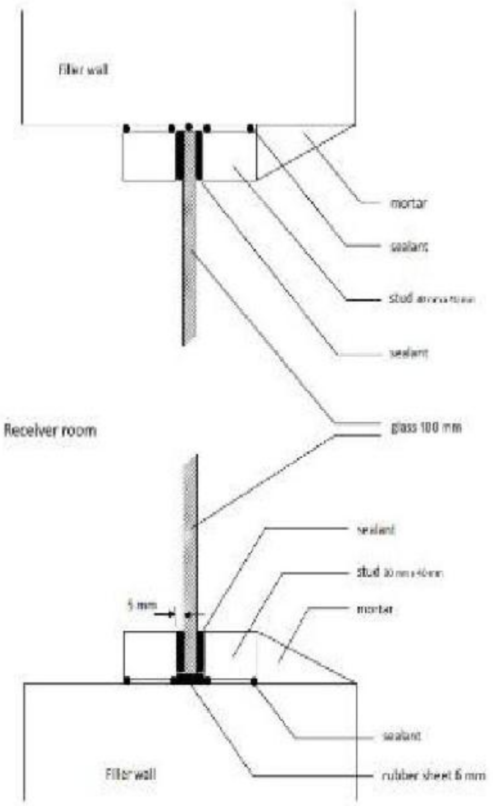


**Fig.3b. Vertical section of A-A'**

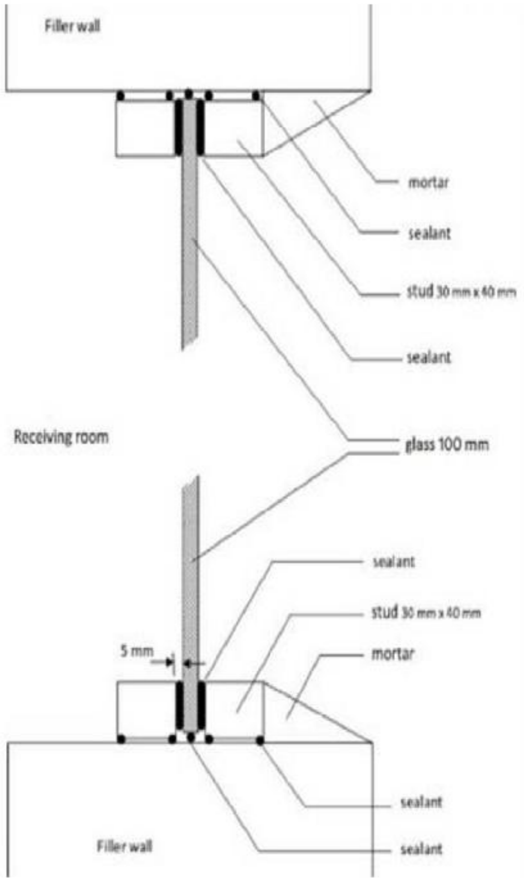


**Fig.3c. Horizontal Section of B-B'**

**Table 2. Glass testing methods**

| No. | Test specimens | Specimen specification | Room temperature (°C) and humidity (%) |
|---|---|---|---|
| 1 | Filler wall | Light brick + mortar, thickness 252 mm, density ± 180 kg/m² | 26 -27°C, 60-90% |
| 2 | Float/flat glass | Asahi, 1100 mm x 1000 mm, thickness 10 mm, density ±25 kg/m² | 26 -27°C, 60-90% |
| 3 | Float/flat glass | Asahi, 1100 mm x 1000 mm, thickness 10 mm, density ±25 kg/m² | 31-32°C, 60-90% |
| 4 | Float/flat glass | Mulia 1100 mm x 1000 mm, thickness 10 mm, density ±25 kg/m² | 26 -27°C, 60-90% |
| 5 | Float/flat glass | Mulia 1100 mm x 1000 mm, thickness 10 mm, density ±25 kg/m² | 31-32°C, 60-90% |
| 6 | Laminated | Asahi, 1100 mm x 1000 mm, thickness 10 mm, density ±25 kg/m² | 26 -27°C, 60-90% |
| 7 | Laminated | Asahi, 1100 mm x 1000 mm, thickness 10 mm, density ±25 kg/m² | 31-32°C, 60-90% |
| 8 | Tempered | Asahi, 1100 mm x 1000 mm, thickness 10 mm, density ±25 kg/m² | 26 -27°C, 60-90% |
| 9 | Tempered | Asahi, 1100 mm x 1000 mm, thickness 10 mm, density ±25 kg/m² | 31-32°C, 60-90% |
| 10 | Frosted | Asahi, 1100 mm x 1000 mm, thickness 5 +5 mm, density ±25 kg/m² | 26 -27°C, 60-90% |
| 11 | Frosted | Asahi, 1100 mm x 1000 mm, thickness 5 +5 mm, density ±25 kg/m² | 31-32°C, 60-90% |

Each glass specimen was tested twice for different set of room temperature (Table 2 and Fig.4). The relative humidity (RH) remained at 60-90% as is daily condition in Indonesia. This RH level is within ASTM standard. Source room was set for 26-27 C and 31-32 C (representing variation of outdoor environment), whilst receiving room remained in 26-27 C (representing indoor environment solely)

**Fig.4. Source room was set for 26-27 C and 31-32 C, receiving room remained in 26-27 C.**

## IV. RESULT AND DISCUSSION

For specimen smaller than the test opening was employed, composite wall calculation was utilized [1]. Transmission loss taken of each frequency of the composite wall then was calculated using the following formulae to initiate TL of the specimen:

$$\tau_c S_c = \tau_s S_s + \tau_f S_f$$
or
$$\tau_s = (\tau_c S_c - \tau_f S_f)/S_s$$

Where
Sc area of composite construction (Sc= Sf+ Ss)
Sf area of filler element
Ss area of test specimen
c transmission coefficient of composite construction
f transmission coefficient of filler element
s transmission coefficient of test specimen
The transmission coefficient of 1/3 octave band were tested to later configure STC of each test specimen.

**Table 3a. Test specimen transmission loss (TL)**

| 1/3 Octave band frequency | Transmission Loss (TL) in dB & STC | | | | |
|---|---|---|---|---|---|
| | Filler element solely | Float/flat glass Asahi | | Float/flat glass Mulia | |
| | 24-26 °C | 24-26 °C | 31-31°C | 24-26 °C | 31-31°C |
| 125 | 37.4 | 25.0 | 22.0 | 24.0 | 20.0 |
| 160 | 32.9 | 27.0 | 28.0 | 27.0 | 27.0 |
| 200 | 36.9 | 25.0 | 26.0 | 25.0 | 25.0 |
| 250 | 40.2 | 27.0 | 27.0 | 27.0 | 27.0 |
| 315 | 37.4 | 29.0 | 29.0 | 28.0 | 28.0 |
| 400 | 43.6 | 30.0 | 30.0 | 29.0 | 30.0 |
| 500 | 44.6 | 31.0 | 31.0 | 31.0 | 31.0 |
| 630 | 48.2 | 32.0 | 32.0 | 32.0 | 32.0 |
| 800 | 49.4 | 32.0 | 32.0 | 32.0 | 32.0 |
| 1000 | 50.9 | 34.0 | 34.0 | 32.0 | 32.0 |
| 1250 | 52.5 | 34.0 | 34.0 | 33.0 | 34.0 |
| 1600 | 54.3 | 31.0 | 31.0 | 31.0 | 31.0 |
| 2000 | 54.9 | 35.0 | 34.0 | 35.0 | 34.0 |
| 2500 | 52.7 | 38.0 | 37.0 | 37.0 | 37.0 |
| 3150 | 53.3 | 40.0 | 40.0 | 40.0 | 40.0 |
| 4000 | 55.3 | 41.0 | 42.0 | 41.0 | 41.0 |
| STC (ASTM E413) | **48** | **34** | **33** | **33** | **33** |

**Table 3b. Test specimen transmission loss (TL) continued**

| 1/3 Octave band frequency | Transmission Loss (TL) in dB & STC | | | | | |
|---|---|---|---|---|---|---|
| | Laminated | | Tempered | | Frosted | |
| | 24-26 °C | 31-31°C | 24-26 °C | 31-31°C | 24-26 °C | 31-31°C |
| 125 | 17.0 | 17.0 | 24.0 | 23.0 | 18.0 | 17.0 |
| 160 | 28.0 | 28.0 | 28.0 | 27.0 | 26.0 | 26.0 |
| 200 | 25.0 | 25.0 | 25.0 | 26.0 | 26.0 | 25.0 |
| 250 | 28.0 | 28.0 | 28.0 | 28.0 | 27.0 | 29.0 |
| 315 | 29.0 | 29.0 | 28.0 | 30.0 | 28.0 | 29.0 |
| 400 | 31.0 | 31.0 | 29.0 | 31.0 | 30.0 | 30.0 |
| 500 | 31.0 | 31.0 | 31.0 | 32.0 | 32.0 | 32.0 |
| 630 | 33.0 | 33.0 | 32.0 | 33.0 | 32.0 | 32.0 |
| 800 | 34.0 | 34.0 | 32.0 | 33.0 | 34.0 | 34.0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1000 | 36.0 | 36.0 | 33.0 | 33.0 | 36.0 | 36.0 |
| 1250 | 37.0 | 37.0 | 34.0 | 34.0 | 36.0 | 37.0 |
| 1600 | 36.0 | 36.0 | 32.0 | 32.0 | 36.0 | 36.0 |
| 2000 | 38.0 | 38.0 | 35.0 | 34.0 | 34.0 | 35.0 |
| 2500 | 41.0 | 41.0 | 37.0 | 37.0 | 28.0 | 28.0 |
| 3150 | 42.0 | 42.0 | 39.0 | 39.0 | 31.0 | 31.0 |
| 4000 | 44.0 | 44.0 | 41.0 | 40.0 | 34.0 | 33.0 |
| STC (ASTM E413) | **34** | **35** | **33** | **34** | **34** | **34** |

By Table 3, we note there is no significant difference in all test specimens. The STCs stay at 33 to 35, which is in term of sound transmission this is considered insignificant. For each specimen, we also note zhat temperature variations did not affect STC significantly. This confirms earlier study that no such temperature variation would affect physical property of glass as long as it below 600 C [3,4]. Beside the STC single number, we may also learn from the STC's curves, which show that in general, the test specimen work effectively as sound insulation for frequency above 1000 Hz, taken one as an example is float/flat glass Asahi (Fig. 5a and 5b). This curve represents all test specimens that has similar curving plot, i.e. effective for frequency above 1000 Hz. We also note dip (drop in reduction) at 1600 Hz. The dip was more significant for frosted glass since two sheets of 5 mm glasses were bound manually on site. This is due to difficulties in getting 10 mm frosted glass on schedule (Fig. 6a and 6b).

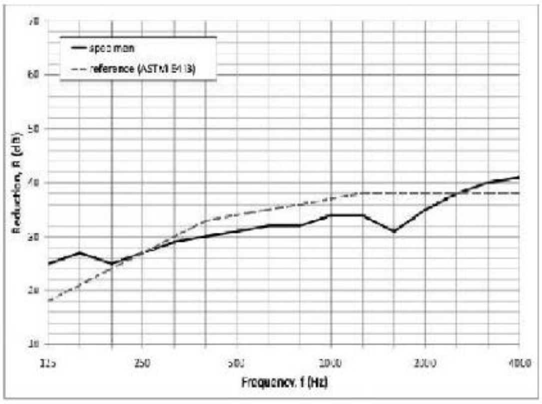


**Fig.5a. STC of float/flat glass Asahi at 24-26 C** (compared to **reference [14])**

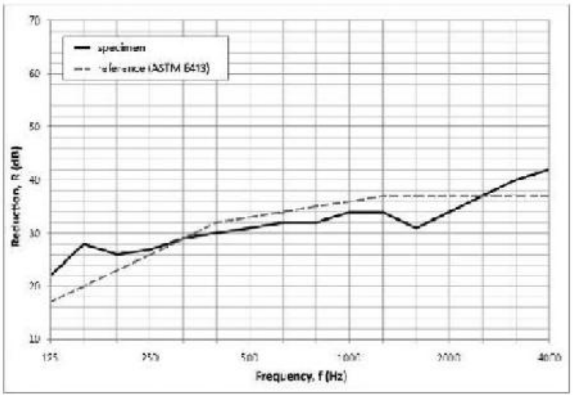


**Fig.5b. STC of float/flat glass Asahi at 31-32 C** (compared to **reference [14])**

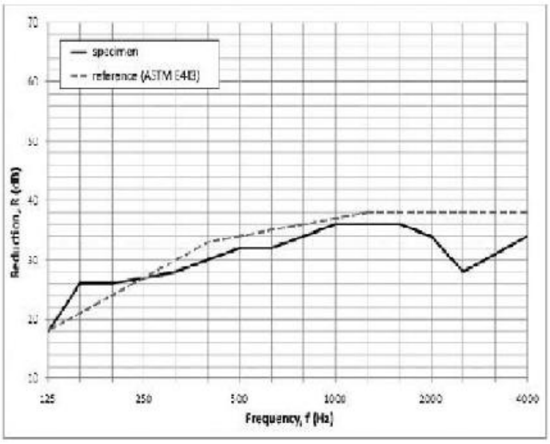


**Fig.6a. STC of frosted glass at 24-26 C** (compared to **reference[14])**

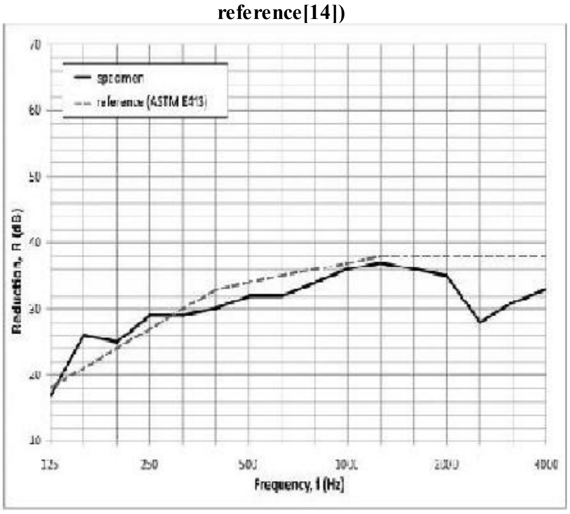


**Fig.6b. STC of frosted glass at 31-32 C** (compared to **reference [14])**

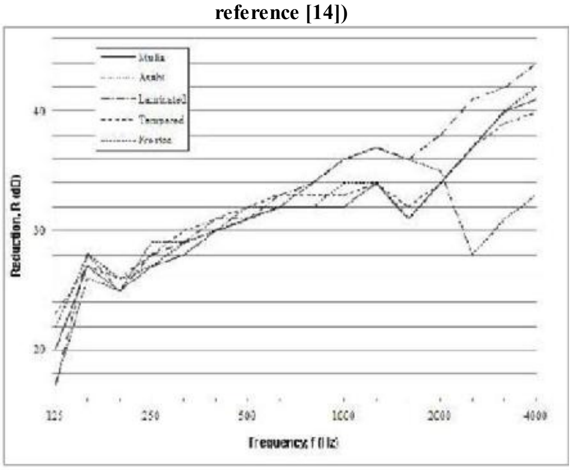


**Fig.7. STC of all specimens at 31-32 C**

When earlier research proven that laminated glass performs better STC compared to float/flat monolithic glass [11,12], Fig. 7 reveals that laminated even performs best STC among monolithic, tempered and frosted. Thin adhesive layers between glass sheets seemed to play significant role in increasing STC and maintaining TL contour. Fig.7 also shows that laminated glass maintains shallowest dip compared to other glass.

## CONCLUSIONS

This study concluded that no significant effect of sound insulation issue was borne out due to variation of air temperature, which only varies by 1. This may become a new reference that temperature variation in test room do not play significant role as long as the temperature has no impact on molecular deformation of the test specimen. Whilst by variation of specimen type (float/flat, laminated, tempered and frosted glass) the STCs vary from 1 to 2. We also may consider this as insignificant. STCs that did not significantly vary for float/flat, laminated, tempered and frosted, has mostly caused by fact that all specimens have similar density of about 25 kg/m2 . Thus we conclude that the most important factors for glazing are still the density. This also works for other solid materials, where density is the most decisive factors regarding STC value. In general, Indonesian glass with density approximately 25 kg/m2 owns STC of 33 to 35. This is similar to Pilkington glass that claimed to have Rw (use in the UK; similar to STC) of 33 (flat glass) and 34 (laminated glass) [11]. Laminated glass produces highest STC among test specimen regardless of air temperature. This study recommends further investigation on glass molecular formation of each specimen toconfront with the variation of the STCs result.

## ACKNOWLEDGEMENTS

This study is fully funded by Ministry of Research, Technology and Higher Education Republic of Indonesia under scheme of Hibah Kompetensi.

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