Influence of acoustic membrane on sound and thermal properties of building façade panels

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Influence of acoustic membrane on sound and thermal properties of building façade panels

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Abstract

This paper compares the acoustic and thermal insulation performance of an extruded polystyrene (XPS) sandwich panel with either one or two additional layers of acoustic membrane of similar overall thickness of 28mm. Samples were prepared by bonding single and double layers of mass-loaded vinyl (MLV) membrane between extruded polystyrene (XPS) core and aluminium facings. Results show that the presence of a single MLV sound barrier layer resulted in a three dB improvement in weighted sound reduction index (Rw) over one-third octave band centre frequency of 100 Hz - 3150 Hz, Rw increasing from 35 dB to 38 dB. The addition of two layers led to an Rw increase of only a further dB to 39 dB. However, the weight of the panel increased from 9.4 kg/m^2 to 13.8 kg/m^2 for the single MLV layer and to 19.2 kg/m^2 for the double MLV layer. The thermal transmission (U-value) with one layer of MLV membrane increased from 1.08 Wm^{-2}K^{-1}to 1.14 Wm^{-2}K^{-1}, an increase of 6% whereas a 12% increase in the U-value was found for the double MLV membrane (1.21 Wm^{-2}K^{-1}) as a result of reducing the thickness of the XPS to accommodate the MLV layers. The addition of MLV membranes, therefore, enhances the sound insulation performance but to the detriment of weight and thermal characteristics.

Key words: Sandwich panels, Extruded polystyrene, Mass-loaded vinyl membrane, Acoustic insulation, Sound reduction index, Thermal insulation

1. Introduction

Modern buildings require facade skins with high sound insulation combined with excellent thermal insulation, lightweight, aesthetics and ease of production and installation. To meet these requirements, sandwich panels made of lightweight core material such as low density foam or fibres sandwiched between two metallic facings are used in building façades. Sound insulation performance of sandwich panels is characterised by measuring frequency dependent sound reduction index (R). Sound insulation performance of typical foam core sandwich panels is not adequate and often require an additional sound insulating layer [1]. Preferably, the sound transmission loss of a sandwich panel have to be improved adequately with minimal effect on the thickness, thermal performance and weight of the panel. However, the additional layers add significant thickness to the overall panel or leads to sacrifices in thermally insulated core thickness to maintain the required overall panel thickness. In middle frequency bands, these sandwich panels demonstrate a dip in R values due to the strong coincidence phenomena which leads to their poor sound insulating performance [1,2]. Typical foam core panels can have sound insulation measured in values around 30 dB [3]. Mostly, mineral wool is used as sound insulation core material but suffer from poor thermal insulation and strength properties.

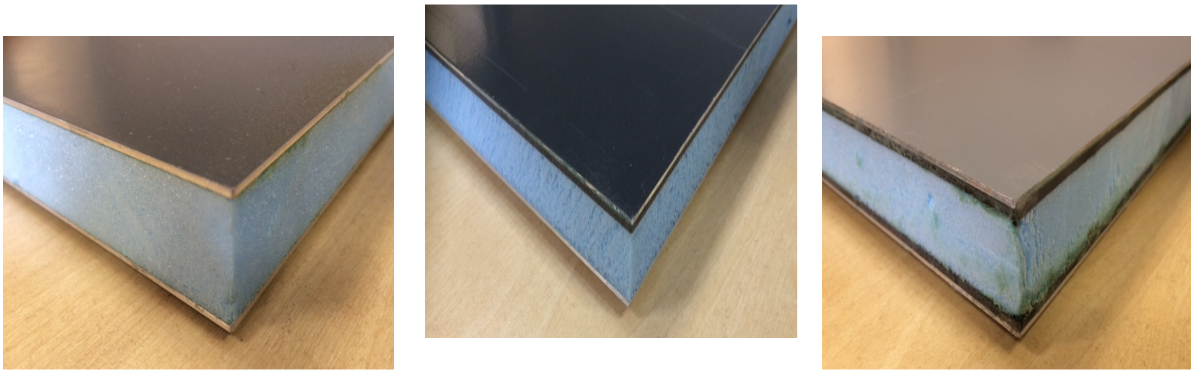
There are other ways to increase the sound insulation of a partition e.g. by adding layers of mass, layers of absorbent material or double or triple layers with or without airgaps filled with absorbent materials [1]. In the simplest terms, the transmission loss of airborne sound from one space to another through a building element can be improved by adding mass and can be claculated by applying the mass law within the building acoustics frequency range 100 Hz -3150 Hz given in BS EN ISO 10140 [4]. Based on the Mass Law, the sound insulation of a single panel will increase by approximately 6 dB per doubling of mass or frequency assuming that the panel acts as a single solid element and undergoes single harmonic motion by the energy of incident sound waves. Mass law can be written as Equation (1) [5,6,7]

$$R = 20\log(f \times m) - K_R \qquad (1)$$

where m is the mass, f is the frequency, K_R is the numerical constant which has the value of 47.3 for random angel of incidence and 42.3 for normal incidence.
This paper investigates the development and experimental assessment of façade sandwich panels developed with acoustic enhancing mass-loaded vinyl (MLV) membranes. One or two MLV membranes were added as mass and damping layers between aluminium facing sheets and extruded polystyrene (XPS) core material and the airborne sound insulation was measured. The effect of the additional layers of MLV membranes on sound and thermal insulation performance of the sandwich panels is established.

2. Integration of Mass-loaded vinyl (MLV) membrane in sandwich panels

In this work, multi-layered sandwich panels were developed with an aim to optimise sound insulation and thermal insulation properties of composite panels. The panels were developed in a sandwich-type structure composed of a MLV (2.25 mm thick) membrane glued between a core of XPS known as Styrofoam and aluminium facings. The function of the multilayer panel was to resist the passage of sound whilst at the same time maintain thermal insulation properties. MLV membranes add mass to the sandwich panel and acts as vibration dampening for aluminium facing while the XPS core is responsible for providing thermal insulation properties. To produce these sandwich panels, MLV membranes were bonded to an XPS core with 35 kg/m^3 density and compressive strength of 300 kPa using a two part polyurethane adhesive. The thickness of the panels was maintained at 28±0.5 mm in order to exclude any effect of thickness on sound reduction properties of the sandwich panel. The two prototypes (AMSA and AMSMA, see Fig. 1 and Table 1 for an explanation of the acronyms) were analysed and compared with the MLV-free standard sandwich panel (control panel ASA, see Fig. 1 and Table 1) to assess the sound insulation variation caused by the integration of the MLV membranes.



(a) (b) (c)

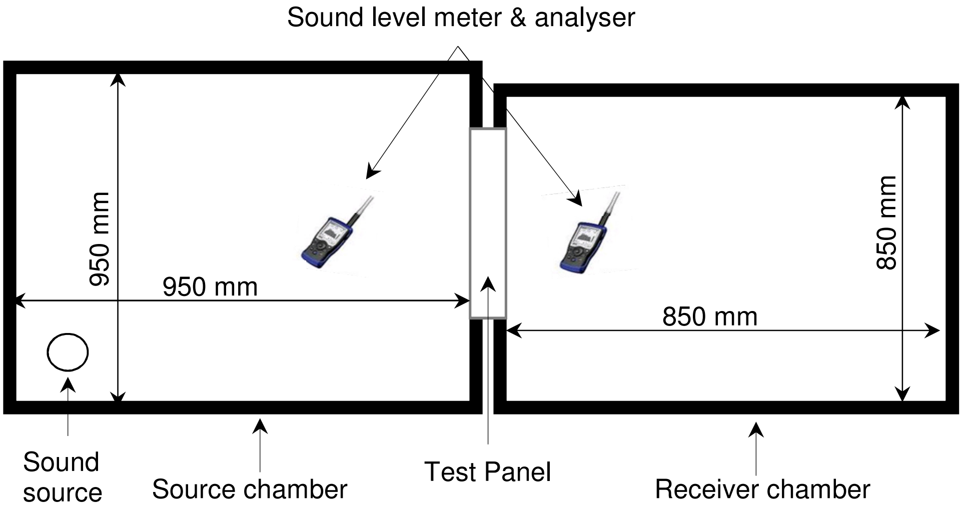
Figure 1: Sandwich panel samples: (a) Aluminium-XPS-Aluminium (ASA) panel; (b) Aluminium-MLV-XPS-Aluminium (AMSA) Panel; (c) Aluminium-MLV-XPS-MLV-Aluminium (AMSMA) Panel

Table 1. Sandwich panel specifications

Sample	Layer					Weight (kg/m^2)	Thickness (mm)	Dimension (mm)
	Facing	Acoustic	Thermal	Acoustic	Facing			
ASA	Aluminium 1.5 mm	-	Styrofoam 25.21 mm	-	Aluminium 1.5 mm	9.4	28.4	566 × 566
AMSA	Aluminium 1.5 mm	MLV 2.25 mm	Styrofoam 22.17 mm	-	Aluminium 1.5 mm	13.8	27.5	566 × 566
AMSMA	Aluminium 1.5 mm	MLV 2.25 mm	Styrofoam 20.50 mm	MLV 2.25 mm	Aluminium 1.5 mm	19.2	28.1	566 × 566

3. Sound Insulation testing of multi-layered panels

Sound transmission loss of the multi-layered panels was measured by the two room method in a small scale laboratory facility. Dimensions of the test chambers are shown in Figure 2.



(a)

(b)

Figure 2: Sound insulation measurement setup: (a) Schematic of the setup; (b) Measurement setup during testing

Volumes of the two chambers are 0.85 m^3 and 0.61 m^3 and size of the aperture is 0.566 m × 0.566 m. Sound pressure level was measured with an NTI XL2 acoustic analyser and M2230 Class 1 microphone. Source room setup with the acoustic analyser and small sound source is shown in Figure 3. Sound pressure level was measured in the source and receiver rooms, each at three different positions for six seconds at least 250 mm apart from each other. Average background sound pressure level was measured in the receiver room for 18 seconds. Reverberation time was measured in the receiver room which is an average of three readings at one microphone position. Sound reduction index (R) was calculated using Equation 2 [8].

$$R = Ls - Lr + 10log(S/A) \qquad (2)$$

where
Ls is the average sound pressure level in source room (dB)
Lr is the average sound pressure level in receiver room (dB)
S is the surface area of common partition or panel (m^2)
A is the equivalent absorption area of the receiver room (m^2) which can be calculated using the Sabine formula $A = 0.161 \times (V/T)$ where V is the volume of the receiving room (m^3) and T is the reverberation time (s).

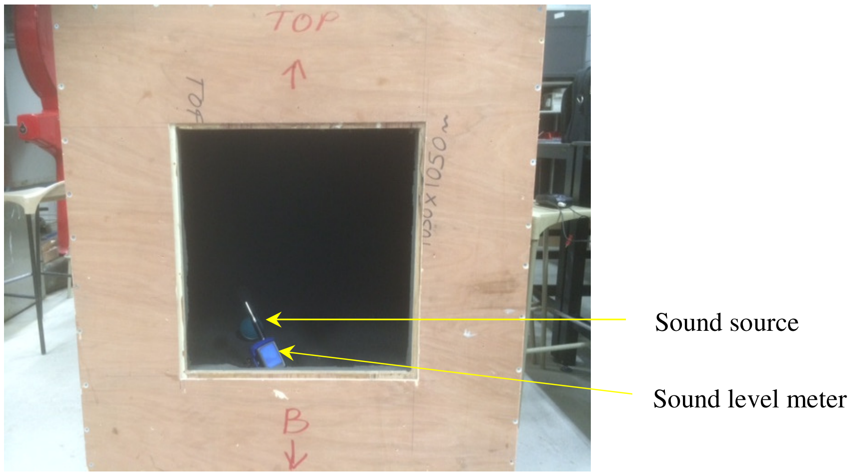


Figure 3: Source room setup

Absorbing condition of the rooms, position of microphones, sound source and averaging time for sound pressure level measurement remained constant throughout the measurement process. Therefore, it is possible to compare the measured results across the different sandwich panels.

4. Results and Discussion

Sound reduction index (R) measurement values of panels ASA, AMSA and AMSMA are shown in Figure 4. Results clearly show that the addition of the MLV layer has led to improvements in the R values of sandwich panels AMSA and AMSMA compared to that of MLV-free ASA panel in the a frequency range of 315 Hz to 3150 Hz. AMSMA sandwich panel has performed better in sound insulation tests due to the addition of two MLV membranes providing higher mass and damping effect compared to that of AMSA and ASA. These results are roughly in agreement with mass law values whereby sound insulation improves by approximately 6 dB per doubling of mass or frequency (the mass increased from the 9.4 kg/m^2 in the control ASA panel to 19.2 kg/m^2 in the AMSMA panel). However, the performance of all samples exhibit a sound insulation dip starting around 2000 Hz, possibly due to the coincidence effect which occurs when wavelength of the sound in the air is same as that of bending waves in the panels.

The values of sound reduction index (R) obtained for different panels at various frequencies does not provide a quantitative comparison of sound insulation of different sandwich panels. BS EN ISO 717-1 [9] was used to quantitatively determine the sound insulation properties of each sandwich panel in a single number i.e. weighted sound reduction index (Rw). For this purpose, a reference curve is given in BS EN ISO 717-1 allocating to each frequency at a standard pressure level. The reference curve is superimposed over the experimentally determined sound reduction index curve and moved towards measured curves in increments of 1 dB until the sum of unfavourable deviations is as large as possible, but never exceeding, 32 dB. An unfavourable deviation at a certain frequency occurs when the measured sound reduction index (R) value is less than the reference curve value. The value of shifted reference curve at 500 Hz frequency, Rw, was obtained for each panel. Rw values of all samples along with sandwich panel weights are shown in Figure 5.

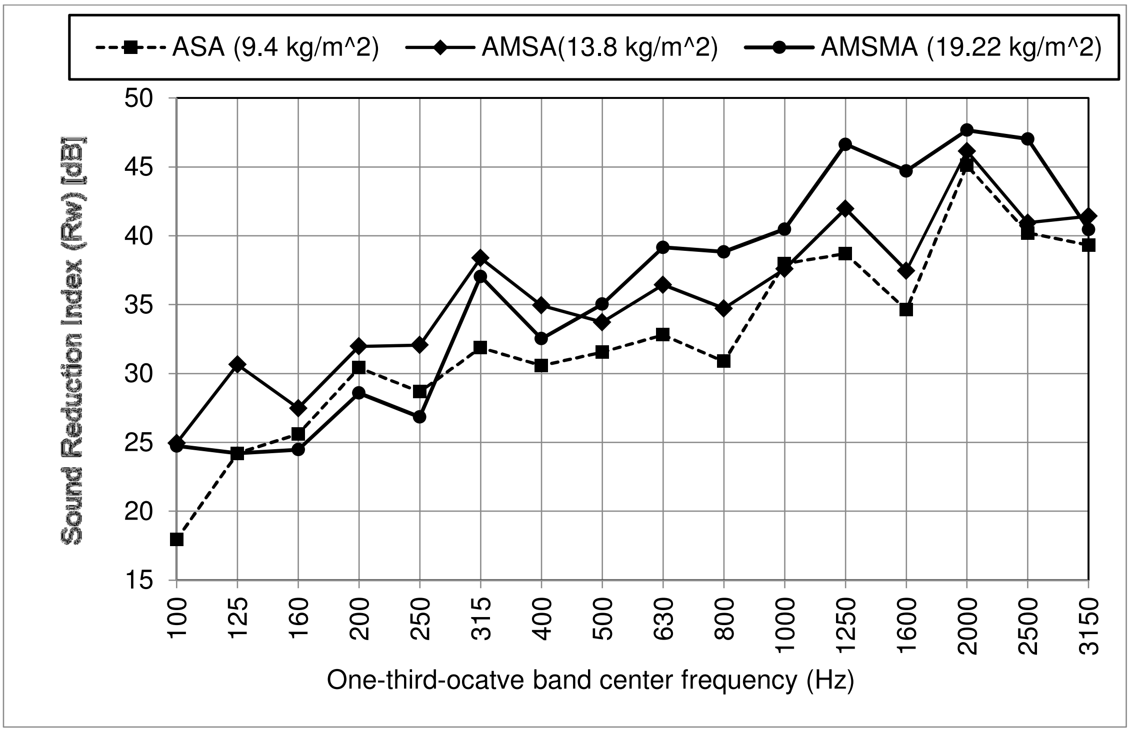


Figure 4: Measured air borne sound reduction index (R) results of different sandwich samples as a function of frequency

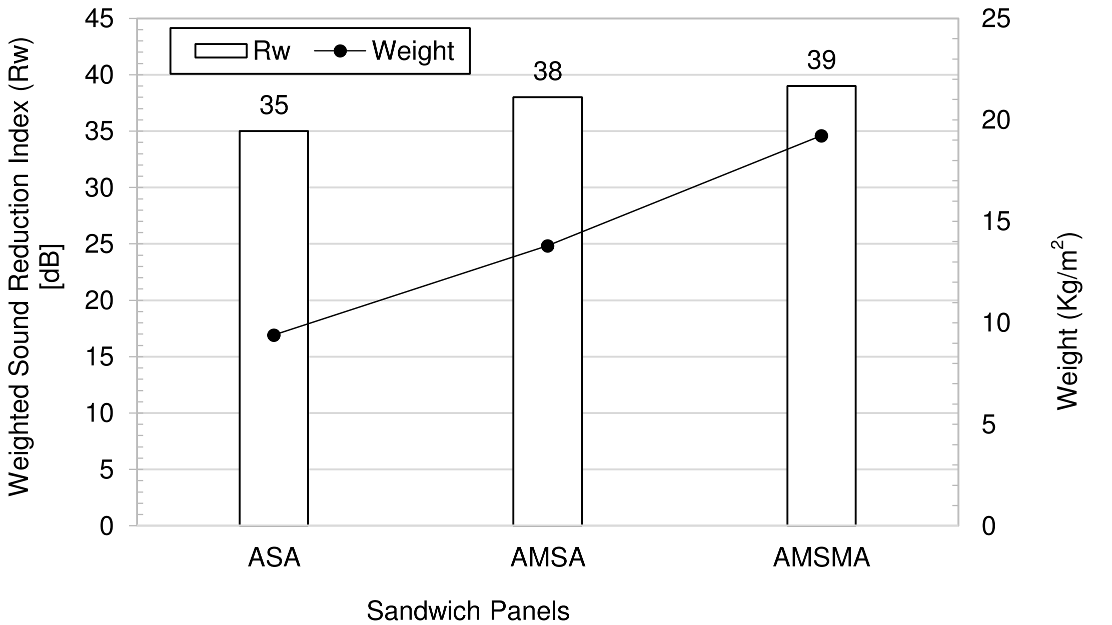


Figure 5: Measured weighted sound reduction index (Rw) and weight comparison of different sandwich samples

From Figure 5, it is possible to verify that the sound insulation of sandwich panels was generally dependent on the mass. In the case of the control sandwich panel ASA with a mass of 9.4 kg/m^2, Rw was 35 dB. With the addition of one MLV membrane, the mass of sandwich panel AMSA increased to 13.8 kg/m^2 leading to an Rw improvement of 3 dB. In the case of sandwich panel AMSMA with two MLV membranes for which the mass was 19.2 kg/m2, its Rw increased by only one dB compared to sample AMSA. However, comparing control sample ASA and AMSMA reveals that the mass has approximately doubled while the total Rw increased by 4 dB. This is slightly lower than when predicted by the mass law where a 6 dB increase in sound reduction index is expected. This behaviour is likely to be as a result of the position of second MLV membrane in panel AMSMA. In sandwich panel AMSA, one MLV membrane was positioned inside the aluminium skin facing the sound source and led to an improvement in Rw by 3 dB with approximately 47% increase in weight compared to control Panel ASA. This aligns with the mass law. However, in sample AMSMA, one of the two MLV membranes was positioned inside the opposite aluminium skin facing away from sound source and led to only a 4 dB improvement in Rw although the weight roughly doubled (increased by 104%) compared to ASA. This shows that it would be preferable to add a heavier MLV membrane at the panel skin facing the sound source as opposed to two lighter MLV membranes as damping layers at either side of the panel.

Traditionally, any acoustic treatment such as the addition of plaster board or use of mineral wool in sandwich panels to improve the sound insulation performance leads to reduced thermal insulation performance or significant addition of overall thickness of the panel [1]. It is desirable that any acoustic treatment of sandwich panels should have minimum impact on thermal insulation performance or on panel design. Therefore, it is important to analyse the effect of any acoustic treatment on the thermal insulation performance of the sandwich panel. In this work, the effect of adding one or two layers of acoustic enhancing MLV has been quantified by comparing their calculated U-value using the thermal conductivity and thickness values of the materials used in the sandwich panels. The control ASA panel has an extra thickness of approximately 2.25 mm and 4.50 mm of XPS foam compared to AMSA and AMSMA respectively in order to keep the overall panel thickness at around 28mm.

As shown in Figure 6, the thermal transmission (U-value) of the sandwich panel with one layer of MLV membrane increased from 1.08 $Wm^{-2}K^{-1}$ to 1.14 $Wm^{-2}K^{-1}$, an increase of 6% whereas a 12% increase in the U-value was found for the double MLV membrane sandwich panel (1.21 $Wm^{-2}K^{-1}$).

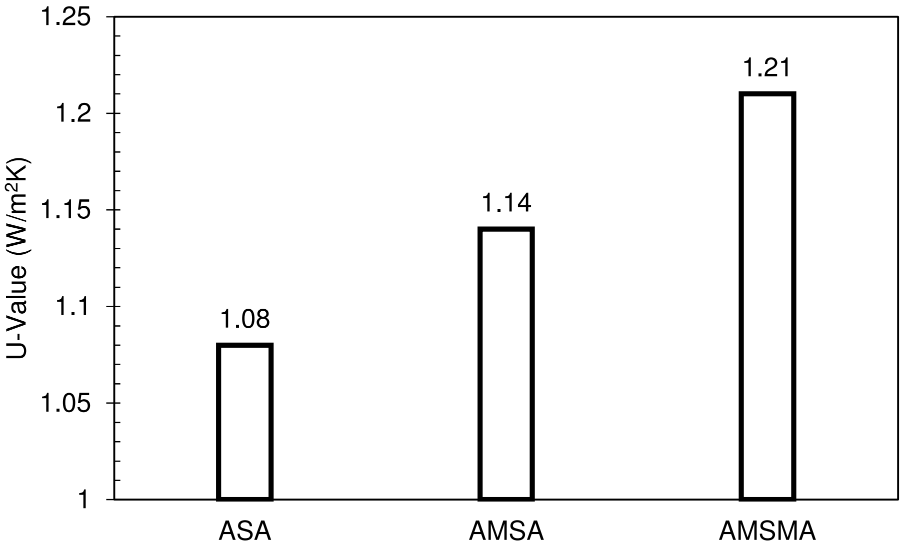


Figure 6: Thermal transmission (U-value) comparison of sandwich panels ASA, AMSA and AMSMA

This is due to the fact that additional thickness of the MLV membrane has replaced a similar thickness of XPS core in samples AMSA and AMSMA in order to keep overall dimensions of the panels the same as the control panel ASA. However, this decrease in thermal performance can be compensated by using core material which has better thermal insulation properties than that of XPS. Such a sandwich panel will have improved sound and thermal insulation performance without an overall increase in thickness meaning they could be used without having to modify or replace existing frames currently used in building facades.

5. Conclusion

In this paper, acoustic and thermal properties of sandwich panels composed of MLV membranes were investigated. The sound insulation performance of sandwich panels was evaluated by measuring sound reduction index (R) in a small scale laboratory facility. The panels with two MLV membranes were found to have the highest values of weighted sound reduction index (Rw) of 39 dB compared to Rw values of 38 dB and 35 dB for sandwich panel with one MLV membrane and without any MLV membrane respectively. This increase in sound insulation was achieved without having any adverse effect on the overall thickness of sandwich panels. Sound insulation performance of the sandwich panels can possibly be further enhanced by adding only one, double-weight MLV membrane at the panel skin facing sound source instead of using two membranes at either side of the panels. Sandwich panel AMSMA with two MLV membrane was calculated to have a U-value of 1.21 $Wm^{-2}K^{-1}$, a 12% drop in thermal performance compared to that of control sandwich panel ASA. Sandwich sample AMSA had Rw of 38 dB while U-value was calculated as 1.14 $Wm^{-2}K^{-1}$. This challenge of a slight decrease in thermal performance can be overcome by using higher thermal performance core material. Such a sandwich panel will not only have good acoustic insulation but also excellent thermal insulation performance but without an increase in thickness.

6. Acknowledgement

The Authors acknowledge the financial and technical support provided by Innovate UK and Panel Systems Limited, Sheffield, UK under a Knowledge Transfer Partnership (KTP) Programme, No. 009433, 2014-2016.

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