PAPER • **OPEN ACCESS**

Characterization of industrial by-products as asphalt paving material

To cite this article: Zulfiqar Ali Jattak *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **220** 012012

Characterization of industrial by-products as asphalt paving material

Zulfiqar Ali Jattak[1], Norhidayah Abdul Hassan[1,2], Nurul Athma Mohd Shukry[1], Mohd Khairul Idham Mohd Satar[1], Muhammad Naqiuddin Mohd Warid[1], Hasanan Md. Nor[1], Nor Zurairahetty Mohd Yunus[1]

[1]School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia
[2]Corresponding author: hnorhidayah@utm.my

Abstract. Most of the recent research is focusing on the utilization of industrial by-products in road construction. The intention is not only to mitigate the problem of waste being dumped to the landfills but to encourage their use as construction material without compromising quality and performance of the road. Steel slag and bottom ash are the industrial by-products generated in large quantity by industry. This study investigates the characteristics of steel slag and bottom ash to be utilized as aggregate in asphalt pavement. Both materials were characterized in terms of physical, chemical and morphological characteristics compared to the conventional granite aggregate. The results revealed that both materials have much potential to be used as aggregate in asphalt mix. The bottom ash was observed weaker in terms of strength, but the steel slag was found much stronger than the granite. The morphological structure of bottom ash and steel slag disclosed that these are made up of porous and rough-edged granular particles with slightly higher water absorption.

1. Introduction

Experts worldwide are trying to develop a sustainable system for future generations as the natural resources are becoming depleted. Concurrently, a massive quantity of industrial by-products is being generated, resulting in quarrying and industrial wastes having a bad impact on the environment. A sustainable system could be achieved if industrial by-products are properly managed and re-used for the construction of roads. It is obvious that most of the problems associated with the strength, durability and performance of pavements depend not only on the characteristics of the binder, but the aggregate used. Over time, the construction industry has consumed a significant amount of raw materials. Simultaneous to industrialization creating a large amount of solid waste deposited in landfills, natural resources are being depleted at an alarming rate. Recent research shows possible and innovative uses of recycling and re-using of industrial waste for road construction.

Recycling and/or reuse of these wastes could revive pleasant environment with the following benefits; preserving natural assets, reduction of solid wastes, saving energy, reduction in air & water pollution and decrease in release of greenhouse gases [1]. Remarkable growth has been noticed in the recycling of industrial by-products for the construction of strategic and ordinary roads in the Northern Italian area. Private companies, highway agencies and public administration are demanding substitute materials that can be used for construction of roads. Thus, more research is required to satisfy the demand, which should be technically practicable, economical and environmentally sustainable [2]. The waste materials can be classified as follows: industrial waste (e.g. cellulose waste, wood lignin, slags, bottom ash and fly ash), municipal or domestic waste (e.g. incinerator residue, scrap rubber, waste glass and roofing shingles) and mining waste (e.g. coal mine refuse) [3,4].

Steel slag (SS) is one of the major by-products generated during the conversion of iron to steel. It is being considered as an ideal aggregate for asphalt concrete pavements because of its admirable mechanical properties. Regardless of positive properties of steel slag in the construction of pavements, its heat retention capacity is longer than the ordinary aggregate used in asphalt concrete [5-7]. The rough texture and particle angularity of this material provide required adhesion and proper interlocking to the aggregates to resist against heavy loading and permanent deformation.

Another waste material, Bottom Ash (BA), is a Coal Combustion Product (CCP). Most of CCP produced in Europe are used in the construction industry, civil engineering and as construction materials in underground mining (52.4 %) or for restoration of open cast mines, quarries and pits (35.9 %) [8]. However, the use of bottom ash in HMA is more recent. The state of West Virginia, between 1971 and 1976, produced more than 200 miles of rural roads using a mixture of bottom ash and bitumen called 'Asphalt', which was followed by the first scientific publication related to the use of this ash in bituminous mixes [9]. Recent studies have indicated that bottom ash may have desirable engineering properties and will not degrade bituminous mix performance properties when used to replace a portion of the fine aggregate in an asphalt mix [10]. The chemical composition of bottom ash consists of silica, alumina and iron including a small percentage of calcium, magnesium, sulfate etc. The main composition, around 88.5 per cent, is composed of (SiO_2+Al_2O_3+Fe_2O_3) [11]. Table 1 represents the chemical composition of locally available materials used by previous researchers.

Table 1. Chemical composition of Granite, steel slag and bottom ash.

Aggregate	Oxide Composition %									
	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	K_2O	Na_2O	SO_3	References
Granite	4.90	64.6	16.8	3.80	0.74	-	4.40	3.48	-	[12]
Steel slag	55.2	10.9	4.0	16.8	3.06	2.59	0.16	0.75	0.85	
Bottom ash	6.34	33.7	12.9	6.98	0.65	-	1.19	0.59	0.90	[13]

This study aims to evaluate the characteristics of Steel slag and Bottom Ash as alternative aggregates in comparison to the conventional granite aggregate.

2. Materials and experimental procedure

Three types of aggregates (granite, EAF steel slag and bottom ash) were used in this research. The natural aggregate was collected from Ulu Choh Sdn Bhd quarry at Pulai Johor Bahru, Malaysia. EAF steel slag was obtained from Antara Steel Mill Sdn Bhd at Pasir Gudang Johor Bahru, Malaysia. The bottom ash was collected from Tanjung Bin Power Plant Johor Bahru, Malaysia owned by Malakoff Corporation. The testing program was purely limited to the characterization of selected materials. Variety of tests were conducted to predict the potential of steel slag and bottom ash as aggregate in place of conventional aggregate for the design of WMA.

2.1 Testing program

2.1.1 Field Emission Scanning Electron Microscope (FESEM)

The morphology of the steel slag and bottom ash including granite (porosity and texture) was examined using field emission scanning electron microscope JEOL JSM-6701F shown in Figure 1. This test was conducted in accordance to ASTM E2090 (2012c). A non-destructive testing setup provides comprehensive information about the morphology and composition of natural and manufactured materials [14].

(a) (b)

Figure 1. (a) JEOL FESEM Microscope (b) specimens coated with platinum.

2.1.2 Specific gravity and water absorption test

The specific gravity and water absorption of selected materials were determined according to AASHTO T85 and AASHTO T84. For the determination of specific gravity and water absorption of coarse aggregate, 1000g of aggregate was immersed in water for approximately 24 hours. The aggregate was weighed in water and then the surface of the particles was dried with a towel and weighed. Finally, the oven dried sample was weighed, and the specific gravity and the absorption were computed. For the specific gravity and water absorption of fine particles, approximately 500g of surface saturated dry sample was taken and the test was conducted using a pycnometer.

2.1.3 Loss Angeles abrasion value (LAAV) test

This test was performed to measure the resistance of aggregates due to degradation and abrasion. Test was conducted as per ASTM C131. The oven dried aggregate of 2.5kg passing from 19mm and retained on 12.5mm and 2.5kg passing from 12.5mm and retained on 9.5mm sieve was transferred in the Los Angeles machine with 11 steel balls. Then it was revolved at the rate of 30 - 33 revolutions per minute for 500 revolutions. The material was then sieved through 1.7mm sieve and the losses were calculated.

2.1.4 Aggregate impact value (AIV) test

The test was conducted as per BS 812: part 112 to examine the resistance of steel slag and bottom ash against sudden shocks compared to the granite aggregate. The washed and oven dried aggregate of 10mm size passing from 14mm sieve was used to perform this test. The tested material was sieved by 2.36mm sieve and the impact value was computed.

2.1.5 Coating and stripping test

This test, in which approximately 200g of aggregate was coated with 5% bitumen, was performed in accordance with AASHTO: T182 (2002b) to examine the adhesion of bitumen with steel slag and bottom ash. The coated specimens were immersed in distilled water maintained at 40°C for 24 hours as shown in Figure 2. The aggregates were then observed visually to estimate the uncoated areas of the aggregate particles as a sign of stripping problem.

Figure 2. Coated specimens of SS and BA immersed in distilled water.

3. Results

3.1 FESEM

The surface scanned morphology of granite is shown in Figure 3. The structural appearance of the granite clearly represents the irregular shaped particles. Despite this, very few pores were observed on the surface and in the particles during the microstructural analysis of the granite. This observation is similar to the observation made by Oluwasola et al. [12].

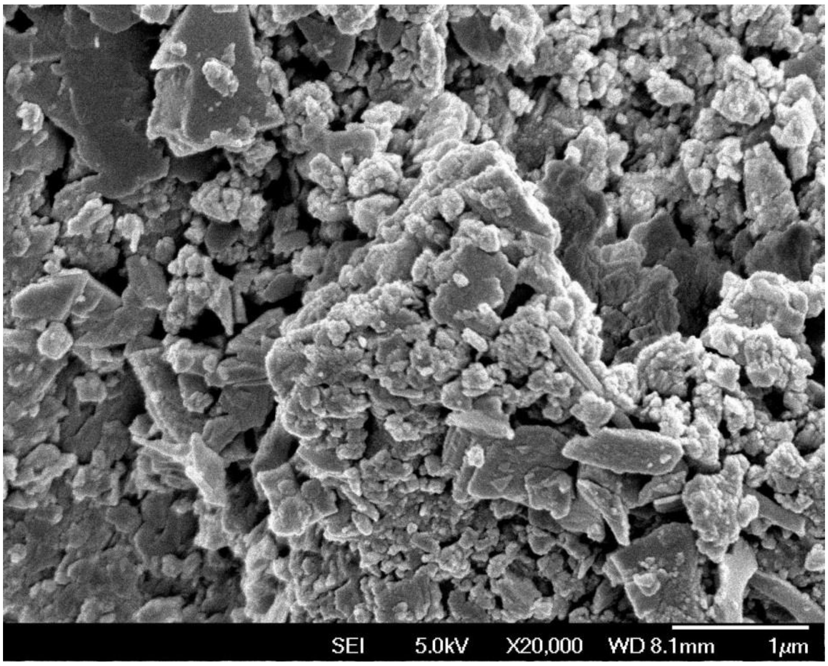
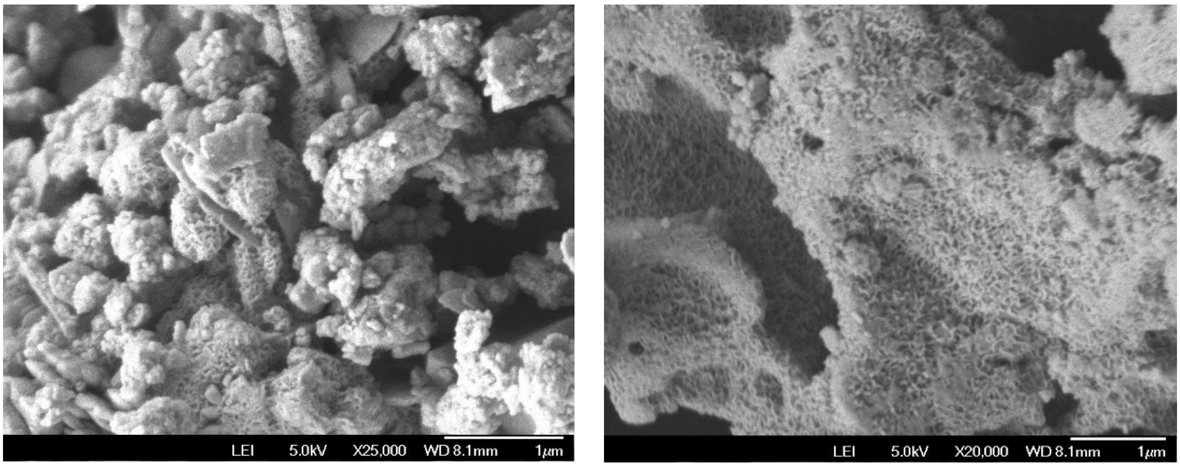


Figure 3. Morphology of granite.

The micrographs of steel slag and bottom ash as shown in Figure 4 represent higher porosity than granite. It can also be observed from the image that the surface texture of both industrial by-products is composed of highly rough and more angular particles. Despite this, the materials show different morphologies and texture from one another. Deep cavities with smoothly connected particles can easily be observed in the photographs of bottom ash represented in Figure 4 (b). A morphological similarity was observed in the micrographs of steel slag compared with the images observed by Ameri et al. [15]. Similar comments have been made by Ramzi et al. [13] when they studied the micrographs of the bottom ash.



(a) (b)

Figure 4. Microstructural morphology of industrial by-products (a) steel slag (b) bottom ash.

3.2 Specific gravity and water absorption

Figure 5 represents the specific gravity of both fine and coarse aggregates. The steel slag contains highest specific gravity compared to granite and bottom ash while the bottom ash consists of lower specific gravity. The presence in greater amount of iron oxide may result in the higher specific gravity of steel slag. On the other hand, the higher carbon content reduces the specific gravity of bottom ash [11]. Chemical composition with low Iron oxide content resulted in lower specific gravity and vice versa.

Steel slag and bottom ash result in comparatively higher water absorption compared to the granite, with the percentage of water absorption in compliance with the range specified by AASHTO. Results are shown in Figure 6.

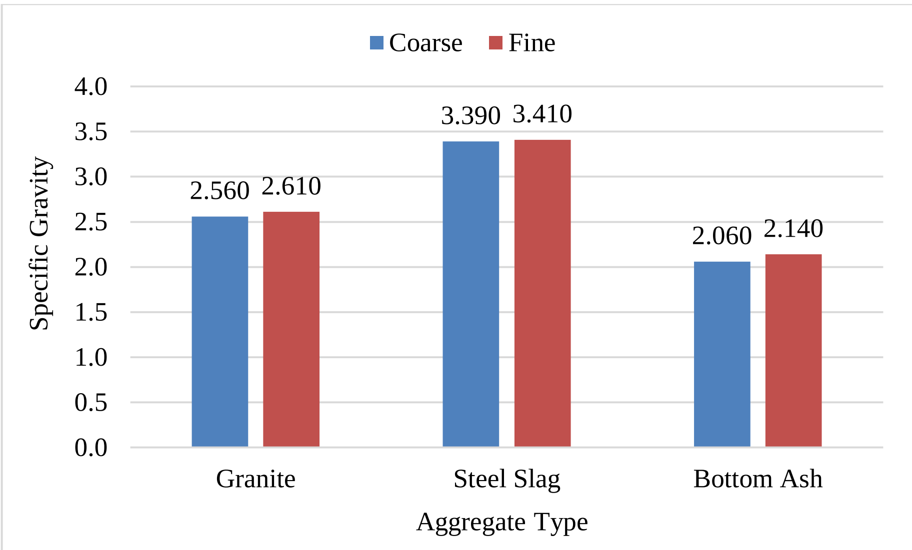


Figure 5. Specific gravity of industrial by-products and granite.

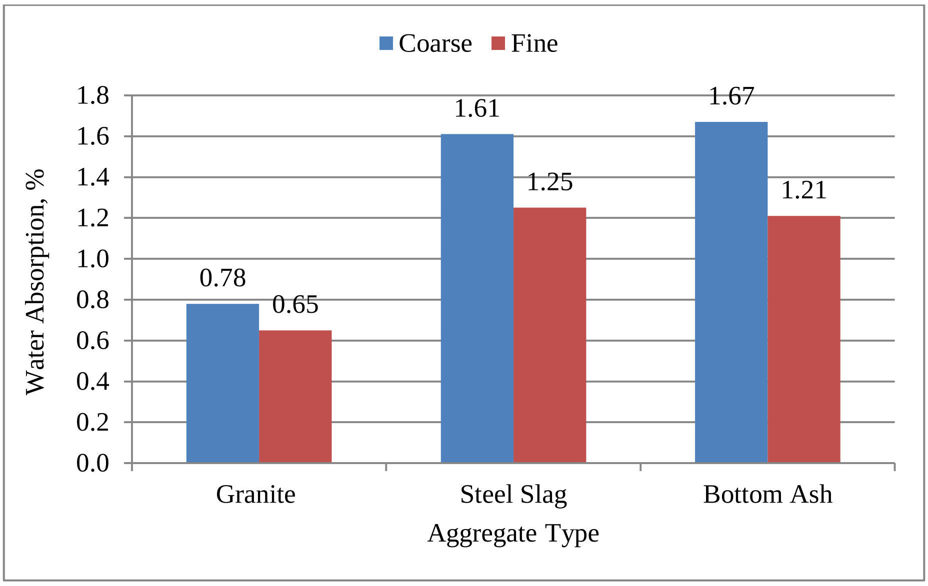


Figure 6. Water absorbed by industrial by-products and granite.

3.3 LAAV and AIV

The resistance of aggregates to abrasion and impact highly influence the durability and performance of wearing course. The aggregates must be tough enough to resist the impacting and grinding forces applied during the manufacturing, placing and compacting of pavement. According to the results observed as presented in Figure 7, the steel slag met the standard specification by providing fewer abrasion loss and lower impact value compared to granite and bottom ash. The bottom ash has provided highest abrasion loss and impact value. Likewise, the granite has shown slightly higher abrasion loss and impact value. According to Kaczmarek [16], the high LAA value produces significantly lower tensile strength resistance and resilient modulus resistance compared to the aggregates having low LAA value.

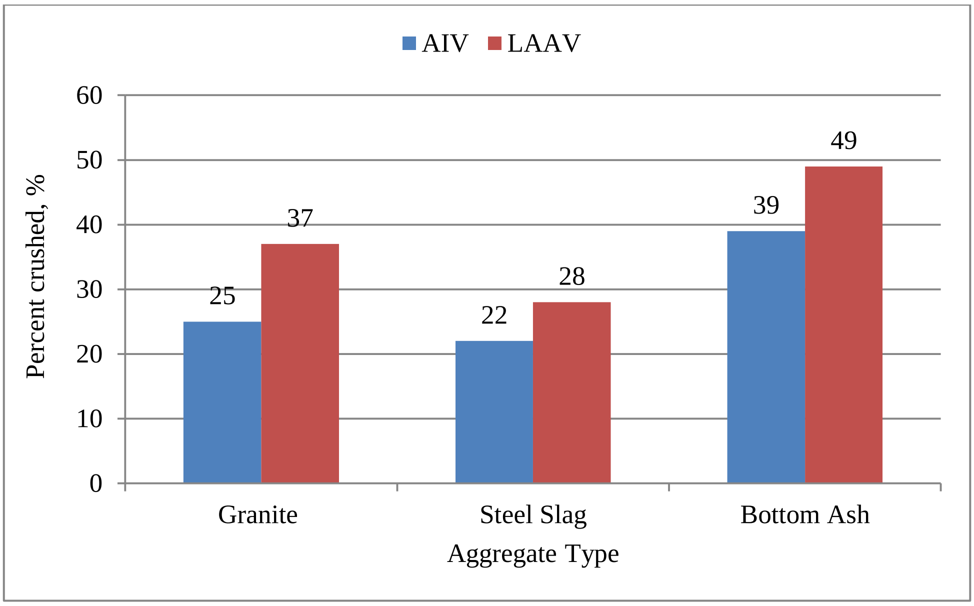


Figure 7. AIV and LAAV results.

3.4 Coating and stripping test
It has been observed that steel slag and bottom ash including granite is having good affinity with bitumen. No stripping of coated binder or detachment of bitumen coating is observed from all type of aggregates. It was generally observed that hydrophobic aggregates facilitate higher resistance to stripping of binder films compared to the hydrophilic aggregates. The chemical basic aggregates are known as hydrophobic, which contain lower silica content. The acidic aggregates are hydrophilic in nature, which exhibit higher content of silica [17].

4. Conclusions
Based on the characterization of the materials, it can be concluded that the presence of lower silica content in steel slag and bottom ash indicates the potential to resist moisture damage compared to granite. Based on the chemical composition, it is predicted that steel slag would improve the performance of asphalt concrete pavements. The rough texture and angular particles of steel slag and bottom ash may increase the adhesion properties and improve the interlocking of aggregates. However, the porosity and higher water absorption of bottom ash and steel slag may slightly increase the optimum bitumen content of asphalt mixes containing these materials. Presence of iron oxide resulted in higher specific gravity of steel slag. This property of steel slag makes it tougher and stronger compared to the granite. The use of steel slag as coarse aggregate may increase the rutting resistance of pavement due to heavy loading. The lower value of losses due to abrasion and impact loading of steel slag favors the use of this industrial by-product as aggregate for the design of asphalt pavement. On the other hand, the high losses of bottom ash due to abrasion and impact loading does not favor the application of bottom ash as coarse aggregate. However, the use of bottom ash as fine aggregate by replacing a reasonable percentage of fine aggregate may overcome the stripping problem caused by moisture susceptibility and may enhance the rutting resistance as well.

5. References

[1] J. J. Bolden IV, Master of Scie thesis, *Innovative uses of Recycled and Waste Materials in Construction Application* (2013)

[2] M. Pasetto, N. Baldo, Road Mater. Pavement De*s*, *Laboratory investigation on foamed bitumen bound mixtures made with steel slag, foundry sand, bottom ash and reclaimed asphalt pavement*, **13 (4)**, 691–712 (2012)

[3] M. R. Hainin, G. Rusbintardjo, M. A. S. Hameed, N. A. Hassan, N. I. M. Yusoff, *J.* Teknol. (Sciences Eng), *Utilisation of steel slag as an aggregate replacement in porous asphalt mixtures*, vol. **69(1)**, 67–73 (2014)

[4] P. Ahmedzade and B. Sengoz, J. Hazard. Mater, *Evaluation of steel slag coarse aggregate in hot mix asphalt concrete*, **165(1–3)**, 300–305 (2009).

[5] H. S. Zeinoddin, S. M. Abtahi, S. M. Hejazi, S. Babamohammadi, A. Goli, M. Amuchi, Transp. Infrastruct. Geotechnol, *Design and Production of Steel Slag Warm Mix Asphalt (SSWMA) Using an Amino-Based Resin*, **3(3–4)**, 91–108 (2016).

[6] M. Amuchi, S. M. Abtahi, B. Koosha, S. M. Hejazi, and H. Sheikhzeinoddin, J. Ind. Text, *Reinforcement of steel-slag asphalt concrete using polypropylene fibers*, **44(4)**, 526–541 (2015)

[7] S. Wu, Y. Xue, Q. Ye, and Y. Chen, Build. Environ., *Utilization of steel slag as aggregates for stone mastic asphalt (SMA) mixtures*, **42(7)**, 2580–2585 (2007)

[8] P. Colonna, N. Berloco, V. Ranieri, S. T. Shuler, Procedia - Soc. Behav. Sci., *Application of Bottom Ash for Pavement Binder Course*, **53(7)**, 961–971 (2012)

[9] S. T. Shuler, *The Effects of Bottom Ash upon Bituminous Sand Mixtures*, (1976)

[10] K. Ksaibati, S. Rama, K. Sayiri, *Utilization of Wyoming Bottom Ash in Asphalt Mixes*, (2006)

[11] G. Vasudevan, Int. J. Res. Eng. Technol., *Performance on Coal Bottom Ash in Hot Mix Asphalt*, **2319(1167)**, 24–33 (2013)

[12] E. A. Oluwasola, M. R. Hainin, M. M. A. Aziz, M. N. M. Warid, Sains Malaysiana, *Volumetric*

properties and leaching effect of asphalt mixes with electric arc furnace steel slag and copper mine tailings, **45(2)**, 279–287 (2016)
[13] N. I. R. Ramzi, S. Shahidan, M. Z. Maarof, N. Ali, IOP Conf. Ser. Mater. Sci. Eng., *Physical and Chemical Properties of Coal Bottom Ash (CBA) from Tanjung Bin Power Plant*, 160(1) (2016)
[14] M. H. Habibi, B. Karimi, J. Ind. Eng. Chem., A*pplication of impregnation combustion method for fabrication of nanostructure CuO/ZnO composite oxide: XRD, FESEM, DRS and FTIR study*, **20(4)**, 1566–1570 (2014)
[15] M. Ameri, S. Hesami, H. Goli, Construction and Building Materials., *Laboratory evaluation of warm mix asphalt mixtures containing electric arc furnace (EAF) steel slag*, **49**, 611–617 (2013)
[16] D. Kaczmarek, *Effects of Los Angeles Abrasion Test Values on the Strengths of Laboratory-Prepared Marshall Specimens*, **6**
[17] A. R. Tarrer, V. Wagh, Transportation (Amst)., T*he Effect of the Physical and Chemical Characteristics of the Aggregate on Bonding*, 31 (1991)

Acknowledgement
The support provided by Malaysian Ministry of Higher Education (MOHE) and Universiti Teknologi Malaysia (UTM) in the form of a research grant number Q. J130000.2522.19H82 for this study is very much appreciated.