Journal of Environment and Earth Science www.iiste.org
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.6, No.9, 2016

The Use of Lateritic Soils as a Cover Material in Municipal Solid Waste Landfills in Nigeria

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Abstract
Classification tests were undertaken on lateritic soils (Soil A, Soil B, Soil C, Soil D) obtained from four borrow pits near the main waste dump being used for the disposal of municipal solid waste (MSW) produced by the residents of Ado Ekiti, Nigeria. Classification according to BS 5930 indicated the soils as clayey SAND (clay of intermediate plasticity). Using AASTHO classification system, Soil A and Soil C were classified as soil type A-2-6 and Soil B and Soil D were classified as soil type A-2-7. The effectiveness of different soil types used as cover material were rated and the different functions of the cover materials in a landfill were ranked according to their perceived importance. Overall rating of the performance of each soil as daily cover and as intermediate cover were obtained from the mathematical computation using the ranking and rating of each soil. The results show that the lateritic soils tested in this study are good as intermediate cover. Although the lateritic soils appear to be fair as a daily cover, it may be used if the clay content is excluded as much as possible.
Keywords: daily cover, intermediate cover, lateritic soil, municipal solid waste landfill, rating, ranking.

1. Introduction

Ever since the use of the term “laterite”by Buchanan (1807), the terms “laterite” and “lateritic soils” have been synonymous with red residual soils consisting of silica, aluminium and iron oxides, derived from the prolonged weathering of different types of rocks under strong oxidizing and leaching conditions. There has been no universally accepted definition for laterite and lateritic soils owing to differing global classification of soils (Morin and Todor, 1976). In particular, there has been conflicting definitions for laterites in the areas of geology, pedology, and engineering. Perhaps one of the most comprehensive descriptions is by Charman (1988) who described “laterite as highly weathered natural material formed by the accumulated concentration of the hydrated oxides of iron or aluminium. The concentration, which could be by residual accumulation of by solution, movement and chemical precipitation is as a result of the secondary physio-chemical processes and not of the conventional primary processes of sedimentation, metamorphism, volcanism or plutonism”.

In all cases, the accumulated hydrated oxides impact the character of the deposit in which they occur and could occur alone in an unhardened soil; as a hardened layer; or as a constituent such as concretionary nodules in a soil matrix or a cemented matrix enclosing other materials. He stated further that the formation of the hydrated oxides of iron and aluminium, are mostly restricted to the humid tropical and sub-tropical zones of the world. Such areas include Africa, India, South-East Asia, Australia, Central and South America. It should be emphasized that, because of shifts of climatic zone in the geological past, important areas of laterite can be found in areas now outside the tropics.

Lateritic soil has been broadly defined as reddish residual and non-residual tropically weathered soils which generically form a chain of materials forming from decomposed rock through clays to sesquioxide-rich crusts (Gidigasu, 1976). A rather precise definition stated laterites as soils with the ratios of silica to sequioxide ($SiO_2/(Fe_2O_3 + Al_2O_3)$) less than 1.33, lateritic soils as those with ratios between 1.33 and 2.00 and non-lateritic soils as those with ratios greater than 2.00 (Lyon Associates Inc., 1971; Ola,1983). To avoid ambiguity, and also in areas where there is lack of adequate laboratory facilities to accurately quantify the ratio of silica to sequioxide, such as in Africa, Ola (1983) localised the definition of lateritic soils as all products of tropical weathering with red, reddish brown or dark brown colour, with or without nodules or concretions and generally, but not exclusively found below hardened ferruginous crusts or hard pan. Similarly, Pinard et al. (2014) in the review of the use of laterite in road construction in southern African countries simply defined lateritic soils as materials that contain less than about 50% (but more than 20%) of the cementing material (iron and aluminium oxides), and/or that has only been modified, and/or that is less well developed, and/or in which the parent or host material is still dominant.

One of the key features of sustainable landfill of municipal solid waste (MSW) is the placement of a cover material at the end of each day to prevent wind-blown litter and odours that cause a problem off-site, avoid attracting scavenging birds to the site and air space above it, and to deter other forms of scavenging. A daily cover (usually 15cm if soil is used) also prevents the attraction and infestation of disease vectors, minimise risk of fire on and within the site, and ensure the visual appearance of the site is not detrimental to the amenity of the locality (Oni, 2009; Environment Agency 2014). The earlier stated function of a daily cover material as a moisture barrier (USEPA, 1992; Tchobanoglous et al, 1993) has been disregarded in recent years owing to its insignificant prevention of total moisture that enters the landfill prior to closure. This does not mean that some covers do not retain some moisture that should have infiltrated the underlying waste layer. An intermediate cover is a landfill cover ((minimum 300 mm if soil is used) that is expected to cover the underlying waste layer(s) for period of time, usually more than 7 days (EPA, 2014). It is expected to perform all the functions of a daily cover and also minimise surface infiltration by shedding surface water to the drainage ditches during the period of use. Not all daily cover materials as suitable as intermediate materials; and vice visa.

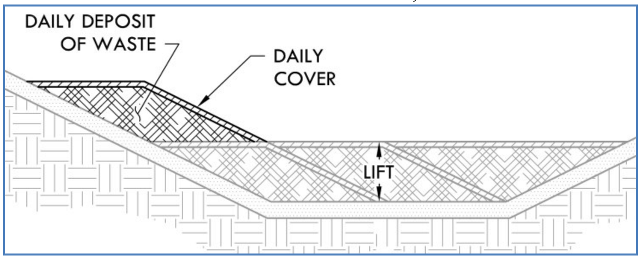

Figure 1: Schematic view of a daily cover.

Soil has been the original and most common type of daily cover as it performs all functions required for a cover to the emplaced waste layer cover reasonably well. It is also convenient to use, being the native soil acquired at the landfill site. However, the stockpile of the native soil soon depletes after several years of landfill operation, especially at large landfill sites, therefore making it necessary for soil to be imported to the site, at a cost. This can be very expensive if the landfill is located in an island where native soil is scarce (USEPA, 1992). It has been stated that up to 25% of the space of a small landfill could be occupied by daily soil cover (USEPA, 1994). If the cost of the valuable space that could have been used by the waste material, but occupied by cover soil, is added to the cost of importing soil to the site, the cost of operating the landfill will increase. In view of this, several materials, which occupy less space than soil have been proposed and used as alternative daily cover (ADC) materials in recent years. Such materials include (i) compost/shredded green waste, (ii) ash, (iii)foam, (iv) sludge, (v) fragmentised waste,(vii) geotextile matting,(viii) colliery and quarry waste,(ix) synthetic mesh, (x) shredded tyre, (xi) geosynthetic fabric (blankets) (xii) pulverised domestic waste and plastic film (Haughty, 2001; Wisconsin Department of Natural Resources, 2014; Environment Agency, 2014).

Apart from the savings accrued through minimal or no space occupied by the ADCs, Adams et al (2011) reported that multilayered bio-tarp consisting of alternating layers of two geotextile were found to remove 16% of methane flowing though the bio-tarp through oxidation by the methanotrophs embedded in the bio-tarp. Similarly, Huber-Humer et al. (2008) reported various biotic systems including daily-used biotarps being effectively used to mitigate landfill methane emissions. Hurst et al (2005) stated that up to 97% reduction of odorous emissions from the underlying waste layer could be achieved by using municipal waste compost compacted to density of 740kg/m^3. van Haaren (2010), using the Life Cycle Assessment, also demonstrated that the use of green waste as a daily cover in a landfills with equipped with gas collection systems is beneficial to the environment.

Nevertheless, there have been issues raised by stakeholders concerning the use of ADCs. Such issues, as stated by California Integrated Waste Management Board (2009) include:

- The optimum amount, depth, and quality of Board-approved ADC may need to be more fully researched.
- It may be difficult to evaluate ADC compliance, and misuse of ADC can go undetected.
- ADC often contains materials that are not allowed in regulation.
- The site-demonstration project requirements for new ADC materials lack guidance which makes it difficult to test new ADC types, such Material Recovery Facility and C&D fines.
- The definition of Green Material in the compostable materials handling regulations is different from the ADC definition of Processed Green Material.
- The Strategic Directive 6.1 of the Board aims to reduce the amount of organics in the waste stream by 50 percent by 2020. Organic waste-derived ADC is considered beneficial reuse, not disposal, which may be a disincentive to keep green material out of the waste stream.
- Using organic materials to reduce greenhouse gas emissions at landfills is currently being researched. The Department of Toxic Substances Control is re-examining Auto Shredder Waste and its reclassification as a hazardous waste would require shredder waste to be disposed in a Class 1 landfill, and not in a MSW landfill.

In the developing countries, the majority of the municipal solid waste (MSW) disposal sites are open dumps, which pose danger to the environment (Kurian et al., 2003, Abdus-Salam et al., 2011). In many of these countries, the enforcement of the use of engineered landfills is either not done or is gradually being done. In Nigeria, there has been awakening of the serious danger the existing dumpsites currently pose to human health and thus several researchers have suggested stabilisation of the abundant native lateritic soil as liners for MSW landfills, in a bid to practise sustainable MSW management (Osinubi et al., 2009; Amadi et al., 2012, Amadi and Eberemu, 2013; Osinubi et al., 2015). However, there has not been any reported investigation on the cover materials, both daily and intermediate, which are also important components of the landfill system. As lateritic soils abound in every part of the country, it is reasonable to study its use as a cover material. Moreover, the use of the ADC materials being utilized in the developed countries is likely to be relatively expensive and unaffordable owing to the existing inadequate MSW technology and landfill infrastructure and poor governmental funding of MSW management projects. The land in which the lateritic soils are located is also relatively cheap. In addition, Oni (2009) reported that ravelling of up to 50% of the daily soil into the underlying waste layer may occur, therefore the space of landfill often reported to be taken up by cover soil may be overestimated.

2. Materials and Methods

2.1 Materials

Lateritic soils used in this study were dug out from borrow pits located close to the main waste dump (Figure 1) being used by Ekiti State Waste Disposal Board (ESWDB) for the final disposal of the municipal solid waste produced by residents of Ado Ekiti, Nigeria. The borrow pits were previously used for the construction of Iworoko –Ado Ekiti road. The lateritic soils lie below the hard crust, which overlie the entire study area; beneath the topsoil. Ado Ekiti is the capital of Ekiti State and lies within the basement complex (igneous rock) rock of south western Nigeria. The granite of Ado-Ekiti, which is commonly referred to as older granite, comprising Migmatite and Charnockites was emplaced during the orogenic cycle that followed early sedimentation. The major lithological rock units consist of coarse grained charnockite, fine grained granite, medium grained-granite and porphyritic biotite-hornblende. The main rock type found in the study area is charnockitic rock which has undergone an intense weathering into reddish to dark brown medium grained lateritic layer of considerable thickness (Ogundana and Talabi, 2014; Okwoli et al., 2014).

The samples obtained were put in protective clean plastic bags and sealed up to prevent exposure to the elements of the tropical weather. They were tagged with letters, A, B, C, and D for identification. Also, the sample number, depth and date of sampling were inscribed on the sheet of paper attached to each plastic bag. The samples were kept in a cool room in the laboratory prior to testing.

2.2 Methods

The classification tests, which comprise the moisture content, particle size distribution, and Atterberg limits were done according to BS 1377-2:1990. The sieve analysis was done using the ISO recommended series of sieve aperture sizes. The compaction tests were undertaken according to BS 1377-4:1990.

3. Results and Discussion

The properties of the lateritic soils obtained from the study area are shown in Table 1. All the soil samples have fines content of more than 30% and plastic index of more than 15%, probable evidence of the cementing material -iron and aluminium oxides. The average specific gravity of the soil samples is approximately 2.53, while the average values of the maximum dry density and the optimum moisture content are approximately 1900kg/m^3 and 13% respectively. These values are similar to those reported for Nigerian lateritic soils (Rahman, 1987; Oyediran, and Kalejaiye, 2011; Onyelowe, 2012).The average hydraulic conductivity is approximately 3.23 x 10^{-4}m/s, which is typical of fine sand (Domenico and Schwartz, 1990). Soil A and Soil C were classified as soil type A-2-6 using AASTHO classification system. Likewise, Soil B and Soil D were classified as A-2-7. Classification according to BS 5930 indicates the soils as clayey SAND (clay of intermediate plasticity). The reddish brown colour of the soils is typical of lateritic soils.

The rating of the effectiveness of different types of soil as cover material in typical MSW landfill is shown Table 2. The rating has been derived from the data provided by Qasim, (1994) and Environment Agency (2014). The rating ranges from 1-4, with 4 being an excellent performance and 1 being a poor performance of the soil for the specific function as a cover material. In order to further assess the effectiveness of each soil for various specific functions as a cover material, the functions are ranked according to how important they are in the achievement of sustainable MSW landfill. A rank of 8 shows the highest priority while a rank of 1 shows the lowest priority

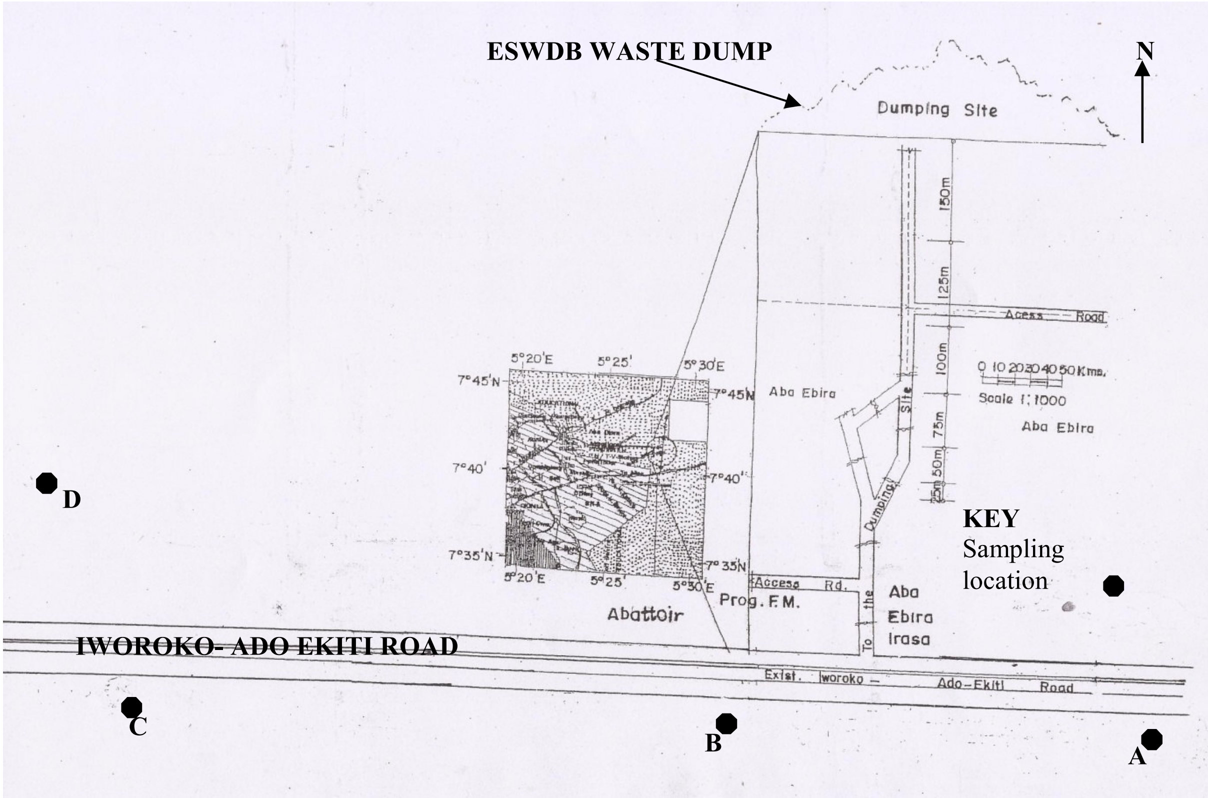

Figure 1: Map showing the study area**.**

Table 1: Properties of the lateritic soils

Properties	Values			
	Soil A	Soil B	Soil C	Soil D
Natural moisture content (%)	28.08	28.13	27.17	19.90
Liquid limit	39.00	42.00	40.00	41.00
Plastic limit (%)	21.99	24.49	21.03	21.90
Plastic Index (%)	17.01	17.51	18.97	18.90
Gravel content (%)	8.20	4.90	6.90	5.30
Sand content (%)	59.14	60.40	59.30	65.50
Silt/Clay content (%)	32.66	34.70	33.80	29.20
Maximum dry density (kg/m^3)	1860	1990	1930	1840
Optimum moisture content (%)	12.69	10.51	14.09	15.00
Specific gravity	2.48	2.36	2.69	2.60
Hydraulic conductivity (m/s)	3.14×10^{-4}	2.06×10^{-4}	4.15×10^{-4}	3.58×10^{-4}
Classification according to BS 5930	clayey SAND (clay of intermediate plasticity)	clayey SAND (clay of intermediate plasticity)	clayey SAND (clay of intermediate plasticity	clayey SAND (clay of intermediate plasticity
AASTHO classification	A-2-6	A-2-7	A-2-6	A-2-7
Colour	Reddish Brown	Reddish Brown	Reddish Brown	Reddish Brown

Table 2: Effectiveness of general soil types as cover material in a MSW landfill (Qasim, 1994; Environment Agency, 2014)

S/N	Function (n)	Rating						Ranking	
		Clean Gravel	Clayey Silty Gravel	Clean Sand	Clayey Silty Sand	Silt	Clay	For use as daily cover	For use as intermediate cover
1	Minimise Litter	3	3	3	3	3	3	8	8
2	Minimise Odour	3	3	3	3	3	3	7	7
3	Prevents rodents from borrowing and tunnelling	3	2	3	1	1	1	6	6
4	Keep flies from emerging	3	2	1	3	3	4	5	5
5	Be permeable for moisture	4	1.5	4	1.5	1.5	1	4	-
6	Be permeable for venting decomposition gas	4	1	3	1	1	1	3	-
7	Fire risk	3	3	3	3	3	3	2	2
8	Provide pleasing appearance	4	3	4	4	4	4	1	1
9	Minimise moisture	1	3	1	3.5	3.5	4		4
10	Minimise gas venting	1	3	1	3.5	3.5	4		3

For the ratings: 4= excellent; 3.5= good-excellent; 3= good; 2.5=fair-good; 2= fair; 1 = poor

The ranking shown in Table 2 has been obtained from average opinion of the stakeholders in Nigeria. It could be seen that the ability of the cover material to be permeable for landfill gas and moisture is ranked higher than the statutory function of being non-inflammable and minimise potential fire, and provide pleasing appearance because the former is a technical requirement, which will enhance the stabilisation of the emplaced waste, as currently practised in modern MSW landfills. The use of impermeable cover material will cause perched water and thus obstruct the removal of landfill gas or leachate.

In order to obtain an overall rating for each soil, a mathematical equation that relates the rating and corresponding ranking is derived and shown in equation 1. This rating is expressed numerically and can be easily compared to rating performance that ranges from 1 (poor) to 4 (excellent). This method makes it easy to present reports on the effectiveness of different soils as a cover material to stakeholders, who have no technical expertise in Geo-Environmental Engineering. Moreover, the allocation of financial funds to MSW management projects usually involves Administrators who want data presented in the simplest way.

$$Overall\ rating = \sum_{i=1}^{i=n} Rating_{(i)} \times \frac{Ranking_{(i)}}{\sum_{i=1}^{i=n} Ranking_{(i)}} \quad (1)$$

The overall rating of various soils as daily cover and intermediate cover is shown in Table 3. It could be seen that clean gravel and clean sand have the highest overall ratings for soils, when used as daily cover. In contrast, these soils have the lowest rating when used as intermediate cover. The overall rating of clayey silty Gravel, clayey silty Sand and Silt are similar for use as daily cover and immediate cover respectively. Clay has the overall rating as intermediate cover.

The comparison of the overall rating of the soils obtained from the study area with the general performance rating of soils as daily cover and as intermediate cover is shown in Figures 2 and 3 respectively. It could be seen that the lateritic soils obtained from the study are relatively good as an intermediate cover. The rating of the soils for use as daily cover is just about fair. It can be seen in Table 3 that soils that have less quantity of silt and clay are most appropriate for use as daily cover

The selection of a cover for the emplaced waste in a MSW landfill is usually a compromise and depends on the operational objectives as relates to stabilisation of the waste and the available facilities at the landfill. Owing to the abundant availability of lateritic soils in the study area, poor landfill practice, and poor government funding of MSW management in Ekiti State, the lateritic soils may be used as daily cover if the clay content (say, clay clumps) of the soil is removed as much possible

Table 3: Overall rating of soils as cover material.

Operational Function	Overall Rating							
	Clean Gravel	Clayey Gravel	Silty	Clean Sand	Clayey Sand	Silty	Silt	Clay
Daily Cover	2.94		2.44	2.86		2.36	2.36	2.44
Intermediate Cover	2.36		2.78	2.36		2.79	2.79	3.03

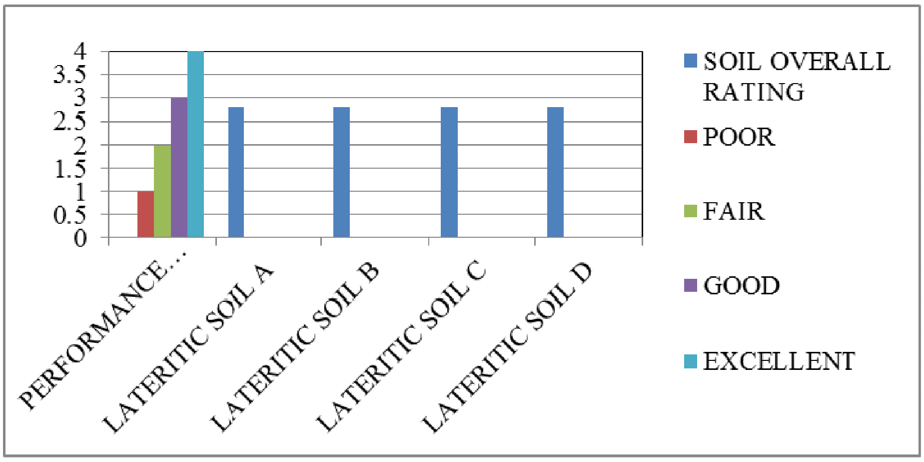

Figure 2: Comparison of overall rating of soils from study area with performance ratings

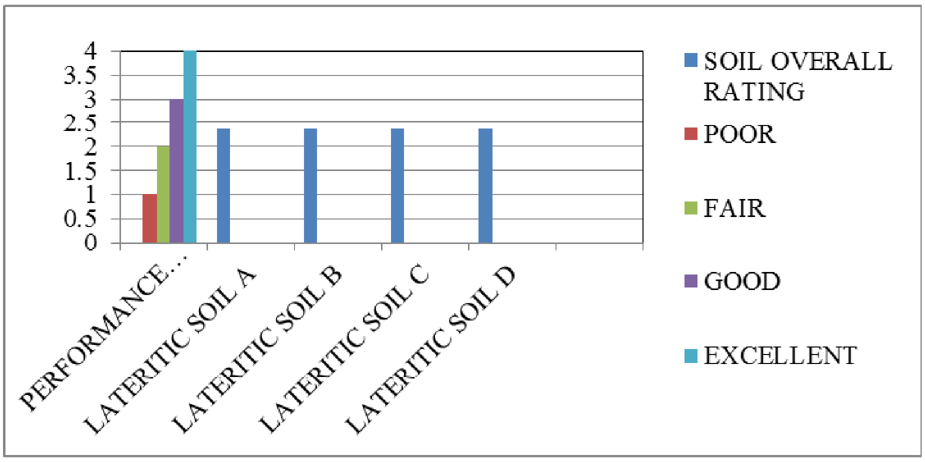

Figure 3: Comparison of overall rating of soils from study area with performance ratings

4. Conclusion

Lateritic soils in the vicinity of the existing sole waste dump used for disposal of the MSW generated by residents of Ado Ekiti were studied for use as a daily cover and intermediate cover respectively in a MSW landfill. Numerical ranking and rating of each soil for its functions as a cover soil enabled the overall rating of each soil to be obtained mathematically and thus compared to the numerical performance ratings of a cover soil, which has been categorised from poor to excellent.

It was found out that the lateritic soils are good as intermediate covers and just fair as a daily cover. However, considering the prevailing conditions of MSW management in Nigeria, it is suggested that the lateritic soils may be used as a daily cover if its clay content is removed as much as possible.

Acknowledgement

The authors are grateful to Omolola Adelugba, Mayowa Ogidi and Muyiwa Oniyinde for their contributions to the success of this paper.

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