Radiation Processing of Municipal Dry Sewage Sludge for Hygienisation and Agricultural Applications

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Abstract
According to CPCB the status of sewage sludge treatment in India is currently inadequate, with most sludge generated being disposed of in dumpsites due to a lack of proper treatment facilities. Despite recent improvements in overall sewage treatment capacity; only a small percentage of generated sludge is actually treated, highlighting a significant gap in management practices across the country. Radiation Technology provides an excellent route to safely and effectively recycling and agronomically use of sewage sludge. Exposure to Gamma radiation effectively kills microorganisms, weeds and degrade chemicals and reduce smell in the sewage sludge. Two such facilities at Ahmedabad and Indore have been recently established. Incorporation of treated sewage sludge (Biosolids) in Fertilizer Control Order (FCO) would facilitate and make available a safe, effective organic manure/soil conditioner to farmers. The government can save some subsidy on chemical fertilizers and environment is largely benefited w.r.t to disposal of sewage sludge and cleaner water bodies. Besides other associated benefits, one ton per hectare use of treated Biosolids with Bio NPK reduces use of chemical fertilizer to the extent of 20% and provide much needed organic carbon to soil. Use of Biosolids provides a few billions of dollar business (2 to 5) in the US, Europe, Australia and part of Asia. India at present does not have any specific regulations for use of sewage sludge in agriculture and other applications.

Key words:
Gamma Radiation,radiation processing, sewage sludge, hygienisation, pathogen, radiation dose, FCO, bio fertilizer, heavy metals, agriculture

Citation
Lalit Varshney - "Radiation Processing of Municipal Dry Sewage Sludge for Hygienisation and Agricultural Applications", *BTRA Scan* - Vol. LIV No.2, April 2025, Page no. 10-17, DOI: 10.70225/404067whtkmf

1.0 Introduction:

Disposal of municipal sewage sludge, especially in large metropolitan cities is an emerging serious problem for urban authorities as sludge contains a high load of potentially infectious microorganisms that can be a serious threat to public health. The present sludge disposal methods have their own limitations. For example, disposal in to sea is site specific, incineration is an extremely energy intensive process and land filling involves transporting the sludge to faraway places because of nonavailability of land in urban areas.

On the other hand, sludge is an important source of macro and micro nutrients such as C, N, P, K, & Zn, Fe, Cu etc respectively. Interest in the use of sludge for application in agriculture has increased among the farming community as well as among the sewage treatment plant (STP) operators. The farming community has realized that the excessive use of chemical fertilizers is not sustainable for long term agriculture and Biosolids can be beneficially utilized for supplying nutrients to the crop, improving soil physical properties and above all increasing the soil organic matter. This can result in increased crop productivity as well as restoration of soil fertility. For STP operators it may offer a way of generating a value added by product from waste whose disposal otherwise is a matter of environmental concerns and economic loss to the nation. Therefore, recycling of the sewage sludge for agriculture application can emerge as an important outlet provided it is carried out in a manner that protects human and animal health as well environment at large (1).

The sludge after conventional treatment processes still contains a heavy pathogenic microbial load and needs to be Hygienised before it is applied to agricultural land. This necessitates development of technologies that can hygienise the sludge in a reliable, efficient and cost-effective manner. Bhabha Atomic Research Centre came out with an interesting technology which can hygienise sewage sludge on large scale (Biosolids) and has set up two facilities at Ahmedabad and Indore in collaboration with the local Municipal Corporations in 2019 and 2023 respectively.

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The high energy Gamma radiation has the unique ability of inactivating microorganisms present in sewage sludge in an efficient and reliable manner. The ionizing radiation emitted by radiation source such as Co-60 interact with the critical molecules like DNA, proteins, fats, carbohydrate and water present in the cell resulting in the inactivation of pathogens. Thus, radiation technology is emerging as an important application in the area of public health. The technology is available locally and Cobalt-60 source is available from Board of Radiation and Isotope Technology (BRIT), Department of Atomic Energy. The facilities can be indigenously constructed under regulation of Atomic Energy Regulatory Board.

2.0 Discussions:

The end product of a standard STP is dried sludge which contain about 75-80% solid and 20-25% water. For land applications It should meet the specified limits for the following characteristics:

1. The presence of pollutants (Arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc). Domestic sewage is not expected to have high concentration of these metals. Ministry of Urban Development has described limits which are similar to norms of United States Environmental Protection Agency (2)

2. The presence of pathogens (e.g. bacteria, viruses, parasites)

3. he sewage sludge attractiveness to vectors such as rodents, flies, mosquitoes, birds etc. which could transfer pathogens to other places and human. .

Table 1. Typical pathogens present in the Fecal sludge and their concentration

Microorganisms	Conc. /100 ml
Coliforms	10^5–10^7
Fecal Coliforms	10^4–10^6
Fecal streptococci	10^4–10^5
Salmonella	1-100

2. Radiation Technology

The advancements in applications of radioisotopes and radiation technologies in various areas like healthcare, industry, agriculture, environment and research have improved the quality of life in many spheres. Radiation sterilization of health care products and food preservation by irradiation are two important applications of radiation technology now playing an important role for the benefit of the mankind. Radiation sterilization using gamma radiation from Cobalt – 60 source is a well-established industrial process in India. Dry sludge can be Hygienised using the same technology and in a similar process. Irradiation plant can be integrated to STP or could be located at different place to serve as a central facility for other STP'S in the region (1).

The Process

The pathogens present in the dried sewage sludge can be effectively inactivated/killed by exposing it to high energy radiation in a fully automatic process as shown in Table 2 and process flow sheet diagram in Figure 1(1). Due to its high penetration property, the bulk sludge can be uniformly treated in large containers or bags. No residues are left and no pollution is created. Therefore, the whole treatment process is environment friendly. Typical irradiation facility features are given in Table 3.

Table 2. Reduction in microorganism number on Irradiation

S.N.	Dosimeter Position.	Radiation Dose (kGy)	Coliform/g	B. Pumilus Spores
1	Control	0	11.5×10^6	1×10^6
2	Minimum	6.85	NIL	0.96×10^2
	Maximum	9.03	NIL	0.3×10^2
3	Minimum	7.07	NIL	0.42×10^2
	Maximum	9.15	NIL	0.16×10^2
4.	Minimum	6.81	NIL	0.85×10^2
	Maximum	9.04	NIL	0.10×10^2

Figure 1. Process flow sheet diagram for 100 tons/day facility

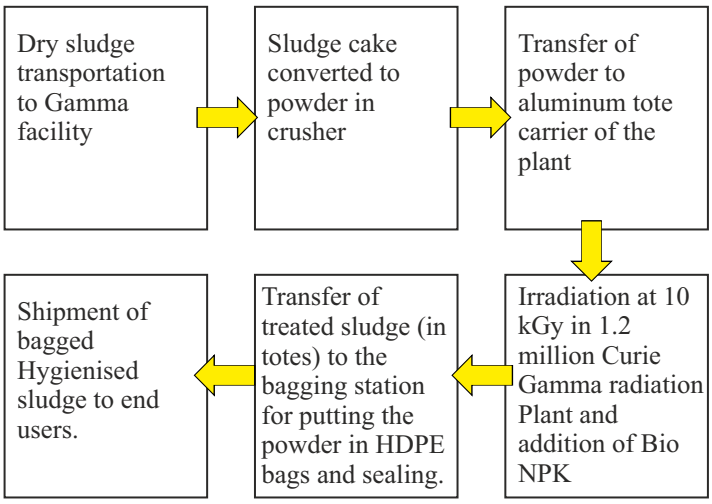

Table 3. Salient Features of Dry Sludge Gamma Irradiation Plant(1)

SR. NO	FEATURE	DESCRIPTION
1	Category of Irradiator	Panoramic wet source storage. Category IV (Ref AERB-SS-6, REV-1, 2008)
2	Products	Dry Sludge (75-80%) solid and 20-25% water
3	Maximum source strength	1.5 MCi (Cobalt-60 Source) of BC188/W31 Pencils.
4	Mode of operation	Product overlap geometry with shuffling outside the cell, with Continuous mode of operation
5	Radiation source Geometry	Rectangular stainless steel source frame with max designed capacity of 3.0 MCi.
6	Source movement system	Hydraulic cylinder with SS wire rope system with requisite safety interlocks.
7	Maximum designed throughput.	5.9 Metric tons / hr. (at 1 gms/cc density) @ 1.5 MCi
8	Radiation dose	10 kGy (Average Dose)
9	Major Sub-systems	• Product Handling System for cell and labyrinth with shuffling feature • Conveyors for loading and unloading area. • Automated crushing & bagging system. • Source Rack with Hydraulic source raise system. • Electrical hoist for source cask handling. • DM plant and pool water conditioning and monitoring. • Irradiation cell Ventilation. • PLC based control and safety systems with SCADA and HMI interface • In cell firefighting. • Pool water chilling system (optional). • Auxiliary conveyor system for sample irradiation (Optional) • Foot print: 4500 m^2 [Cell Area Approx. 400 m^2]
10	Processing (Irradiation cost only)	Rs 1.5/kg in bag of 50 kg, based on 100 tons processed per day.

3. Value addition to Biosolids by addition of bio NPK

On irradiation, bacterial load is significantly reduced. Addition of useful bacterial culture to the Biosolid makes it a useful product increasing it potential to add nutritional value to soil. Due to lower competition, the added bacterial culture shows enhanced growth as shown in Table 4. The slow release of Phosphate and potash in the Biosolid is enhanced due to the presence of corresponding mobilizing bacterial culture. The improved Nitrogen fixation also helps in increase in quality parameter of the treated Biosolid. Increased carbon, micronutrients and soil conditioning results in increase of soil fertility. The proposed specifications for treated Biosolids is given in Table 5.

Table 4. Typical Growth Pattern of useful bacteria in the dry sludge (1)

Useful Bacteria	Inoculated in non-irradiated sludge (CFU/gram)	Inoculated in Irradiated Sludge (CFU/gram)
Phosphate solubilizing bacteria	3x 10^9	5x 10^{11}
Rhizobium	2.5 x 10^8	2.5 x 10^{11}
Azotobacter	4 x 10^9	2.5 x10^{12}

Since there are large variations expected in pollutant levels and Nutritional components in Biosolids, minimum values have been chosen for N, P, K and organic carbon so that a reproducible, well characterized product is made. The specifications are similar to bio compost (FCO) except heavy metal levels (7).

Table 5. Proposed General specifications for Biosolids

Parameters	Specifications
Moisture, percent by weight (Gravimetrically)	Maximum 25
Particle size	Minimum 90% material should pass through 4.0 mm IS sieve
Bulk density (g/cm^3)	<1.0
Total organic carbon as percent by weight	Minimum 12
Total Nitrogen (as N), Phosphate as P_2O_5 and Potash as K_2O, per cent by weight.	Minimum 1.2
C:N ratio#	<20
pH	6.0 – 7.5

Table 5 continue.....

Parameters	Specifications
Conductivity (as dsm^{-1}), not more than	5
Pathogens including Helminths Ova	Not Detectable
***Heavy Metals (Maximum)** Arsenic (As) Cadmium(cd) Chromium (Cr) Copper (Cu) Mercury (Hg) Nickel (Ni) Lead (Pb) Zinc (Zn) *US EPA 40 CFR part 503 for EQ sludge, #Due to variation in sludge	(mg/kg) 41 39 1200 1500 17 420 300 2800
PGPB not less than	**10^7**spores or cyst per g of dry sludge at ambient temp. at the time of production.

4. Outcome of the Radiation Hygienisation process:

The results of radiation processing of dry sewage sludge results in Biosolids which are effective and safe to use (1,2,46,8) and recycled in environmentally friendly manner.

- An average radiation dose of 8-10 kGy has been observed to hygienise dried/solar dried sludge. as recommended for Class "A" Biosolids". The Hygienised sludge in bagged form can be distributed and can be stored for longer time. The quality of sludge processed is equivalent to United States Environmental Protection Agency (2) Exceptional Quality Biosolids which does not require further regulation for use in agriculture applications.

- Sludge treated by radiation processing therefore will not add to the pathogen load of the environment and will not present any risk to the human, animal or crop health. Efficacy of the process is shown by killing of radiation resistant Bacillus Pumilus spores. No smell and weeds are the added advantage.

- Due to reduction in microbial counts, the Hygienised sludge can be inoculated with useful bacteria to give value added biofertilizer.

- It can be blended with other chemical fertilizers and bioproducts and distributed in bags.

The pollutants level in Biosolids is regulated/tested before radiation processing, Due to use of limited quantity of EQ sludge and dilution in the soil, the concern of pollutants is minimized. The use of Biosolids in advanced countries at much higher scale based on their standards evidences its safety and use.

5. Why Radiation Processed Biosolids should be included in FCO (Fertilizer Control Order) for agriculture applications.

The major concerns of the authorities for not including it in FCO are:

1. Presence of pathogens
2. Presence of heavy metals
3. Presence of organic pollutants like drugs, pesticides, poly chloro-flouro compounds, microplastics, nano materials etc.

World over more than 50% of treated sewage sludge (Biosolids) are utilized on land applications. Its use is commercialized in developed countries. Some of those countries include USA, Australia, 27 countries in European Union, UK, Japan, China, South Africa etc. (Table 6). The use of sewage sludge is regulated as per the countries norms most of which are similar to USEPA 40 CFR 503 as shown. For unknown reasons, there are no specific regulatory standards for use of Biosolids in India. Biosolids use is also not included in FCO which could provide much needed organic carbon to soil. It is also an environmental concern if not disposed/recycled properly. India generates about 52644 MLD of sewage with a potential of generating 1.5 lakh tons of sludge per day (5). The sewage treatment present capacity is only 31886 MLD which is growing with coming years. More than 65% of sludge is unused and remaining is used on land applications, biochar and others. Sewage sludge is known to contain significant quantity of organic carbon, micronutrients, Nitrogen, Potassium, Phosphorous and soil conditioning properties. Practically no technology is being used in India to recycle sewage sludge. Lot of research has been done in India and abroad on the subject and many countries have formulated their standards. India has yet to come out with standards.

Table 6 gives the standards formulated by various pollution control agencies including that of India I. It is observed that there are specific regulations for using sewage sludge in agriculture applications. The studies carried out in India clearly demonstrate that:

1. Only dewatered sludge classified as Biosolids s A or B should be used. The heavy metals concentration and pathogens in the sludge should meet regulatory requirement. Class A Biosolids from Sewage Treatment Plants are suitable for organic farming and have fertilizing potential. Such sewage sludge could be used for commercial purpose (6).

2. Most of the regulations are based on USEPA 40 CFR 503. Standard stipulate not only quality but quantity of biosolid use is regulated based on the pollutant load. Sludge crossing ceiling concentration of pollutants should not be used on land application.

3. There is no regulation in FCO over use of compost or organic manure in terms of quantity. In general, 5 tons per hectare of compost is recommended for agriculture applications. Organic bio compost cost about 30-50 Rs/kg.

4. India used about 35 million tons of Urea in agriculture in 2022-23. The Urea subsidy for 2024-25 stands at Rs 1.22 trillion which is about Rs. 35 per kg. Use of Biosolids could save some subsidy and recycle sludge in the safest manner, reduce use of chemical fertilizer and increase productivity. Due to dilution factor in soil, the concern of pollutants would be minimized without effecting the yield as demonstrated by research in India.

5. India has a sludge generation capacity of approx. 7.3 kg/capita/year on dry basis. With 1.4 billion people, the sludge generation per year is about 10 million tons. Taking example of Delhi, with 330 million population process about 2000 MLD of sewage every day leading to generation of about 500 tons dry sludge each day or 182500 tons /year Using one ton per hectare of biosolid comes out to be equivalent to cultivation of 182500 hectare of land per year (9). Urea at 120 kg of per hectare would require about 21900 tons. Saving of 20% Urea means about 4380 tons of urea which is equivalent to government subsidy of about (35x 5600000) 15 crores a year from Delhi alone. Environment cost, health cost and increased productivity cannot be calculated. Since treated Biosolids are good biofertilizer would have commercial value. Otherwise, disposal cost would be much higher along with the health risk. The chances that the untreated sludge going back to water bodies are high.

   In spite of established success of the technology, the availability of Biosolids (treated sludge) to farmers is limited due to non-inclusion in FCO. Inclusion in FCO would increase awareness and channels to sell the product in market and help in recycling of safe sewage sludge. Other available options are not environment friendly. Using the treated sludge could provide great benefits to all including farmers, STP operators, health and environment.

It can be seen from Table 6 that Fecal coliform, salmonella and helminths ova are serious health concern. Irradiation kills all of them with high reliability. Also, Foul smell is reduced, weeds inactivated and persistent organic pollutant degraded to some extent. It may be noted that sewage sludge drying process itself drastically reduces volatile organic compounds.

Table 6. Various regulations followed by pollution control agencies

Country	Microbiologial class	Application/ Reuse	Salmonella	Helminth Ova	Faecal Coliform	E.coli
India (MoUD 2013, CEPT 2015) (Adapted from US EPA, Class A biosolids, WHO 2006)	Dewatered sludge to be used as fertilizer or soil conditioner in agriculture as per MoUD 2016, USEPA and WHO 2006.	Fertilizer or soil conditioner in agriculture.	<3 MPN/4 gram of total dry solid	<1 /gram of total dry solid	<1000 MPN/ gram of total dry solid	<1000 / gram of total dry solid
India (CPHEED 20135, Adapted from US EPA criteria of class A Biosolid).	Dewatered septage/sludge to be used as fertilizer in agriculture	Reuse in agriculture	<3 MPN /4 gram of total dry solid		<1000 MPN/ gram of total dry solid	
WHO 2006	Faecal sludge	Reuse in agriculture		<1 /gram of total dry solid		<1000 MPN/4 gram of total dry solid
US EPA	Pathogen Class A (Ceiling concentration for all biosolids applied to land)	For all biosolids applied on all land types, agriculture, forest, reclamation sites, lawns and home gardens.	3 MPN /4 gram of total dry solid	<1 / 4gram of total dry solid	<1000 MPN/ gram of total dry solid	
US EPA	Pathogen Class A or B (Ceiling concentration limits for EQ and PC biosolids)	For applications in agriculture land, forest and reclamation sites	3 MPN /4 gram of total dry solid		1000 MPN/ gram of total dry solid(A) or 2x 10^6 MPN/CFU per gram dry solid(B)	
South Africa	Unrestricted use qualifies for agriculture	Can be used for all types of crops		1 ova/ 4gram of dry solid	<1000 CFU/ gram of total dry solid(5 log reduction)	

Table 7. Toxic metals limits in Biosolids as per US EPA/ MoUD and in dry sludge samples

Pollutant	Ceiling Concentration limits* (mg/kg)	Annual pollutant loading rate Limits per 365-day period (kg/hectare)	EQ Sludge Heavy Metal Load (mg/kg)	Delhi (Okhla, 560 MLD STP) Sludge Heavy Metal Load (mg/kg)	Indore Smart City STP sludge (mg/kg)
Arsenic	75	20	41	22.4	BLQ
Cadmium	85	1.9	39	BQL	BLQ
Chromium	3000	150	1200	28	BLQ
Copper	4300	75	1500	148	40.3
Lead	840	15	300	30	8.37
Mercury	57	0.85	17	0.05	
Molybdenum	75	--	--		-
Nickel	420	21	420	15	BLQ
Selenium	100	5.0	36		
Zinc	7500	140	2800	368	110.9
Applies to:	All biosolids that are land applied	Bulk and Bagged biosolids	Bulk and Bagged Biosolids		

As per US, EPA, if limit for any one or all exceeds then Sludge cannot be applied on land. EQ sludge as per can be land applied without any further regulation and can be distributed in bags: MoUD Ministry of Urban Development, CPHEED: Central Public Health and Environmental Engineering. BLQ: Below Limit of Quantification

There are large variations in the maximum and minimum values of studied heavy metal loads in various samples of sludge. These variations are expected. As such heavy metal load and other pollutants should be minimum in domestic sewage sludge. However, industrial units and other routes contaminate sewer lines to which government need to regulate and control. To have minimum adverse effects of the biosolids (treated sludge) in the soil and utilizing their agronomical values, one can consider: -

1. Not to use sludge as replacement of chemical fertilizers. Use of 80 % chemical fertilizers and one ton per hectare Biosolids per crop would be useful for long term use of Biosolids. No significant changes in heavy metal loads have been observed even at 5 tons/ hectare (10)

2. Use of Bio NPK increases its agronomical value and mobilizes slow releasing nutrients.

3. For example, for wheat crop 80 kg, 40kg, 40 kg of N.P, K respectively can be replaced with 64 kg,32 kg, 32 kg of NPK and one metric ton of Bio NPK Biosolids. Due to large variations of NPK in Biosolids it could be impossible to know exact values every time of its use. Use of Biosolids increases soil fertility, organic carbon, micro macronutrients, soil structure, retention of chemical fertilizer and microbiological activity and consequently increasing crop yield as observed in many research studies.

4. Use of limited quantities of treated Biosolids addresses the concern of pollutants and benefits, farmers, government and environment.

Table 8. shows the results of study carried out by Centre for Science and Environment on 46 STPs of India in different states. The mean values, minimum and maximum values show large variations from sample to sample as the material is not based on some fixed formulation of its constituents (8). Some values are higher than FCO values but much lower to US EPA values and European Directives. The values in USEPA and European directives for heavy metals are much higher but sludge are permitted there for agriculture/land applications. Certainly, the limits are based on several studies in those countries and ill effects of use of such sludge is not observed. Similarly, evidences are not available for ill effects of persistent pollutants either including microplastics in soil crops.

Table 8. Average heavy metal load in biosolids of 46 STPS in India

Metal	Average mg/kg	Maximum mg/kg	Minimum mg/kg	Limit For Organic Manure by FCO mg/kg	US EPA EQ Sludge mg/kg	EU Directive 86/278/EEC (11)
Hg	1.5	5.9	0.0	0.15	17	16-25
As	1.0	4.7	0.0	10	41	-
Cd	2.8	5.4	0.1	5	39	20-40
Cr	7.6	443	10.4	50	1200	-
Cu	236.4	47	23.2	300	1500	1000-1750
Ni	30.9	68.8	7.6	50	420	300-400
Pb	36.5	104.9	4.6	100	300	750-1200
Zn	140.4	5658	48.6	1000	2800	2500-4000

Using a ton of biosolid per hectare as per USEPA (EQ sludge) along with chemical fertilizer not only would improve soil fertility but also the concern of pollutants in the sludge are significantly reduced due to dilution in soil. The actual pollutants level in Indian Biosolids are observed to have much lower concentration of pollutants than stipulated by USEPA. Using USEPA norms absolves the concern of observed variations in the biosolid for its practical use (Table 8).

Therefore, FCO should consider adopting USEPA norms for Biosolids for agriculture use. The results and discussions in the present manuscript indicates that radiation technology process for treatment of Sewage Sludge is ;-

- Simple, economic, effective, reproducible and scalable .
- Easy to integrate with conventional process in the existing sewage treatment facility and can also be used as central facility for other STP's in the region.
- Total indigenous technology to design, commission and operate the plant, fully automatic to avoid manual handling of contaminated sludge.
- Based on the process of radiation sterilization which is well established world over and in India.
- Hygienised sludge is a potentially useful organic manure as well as good substrate to produce bio-fertilizer to the required standards thus offering the much-desired micronutrients and carbon to the agricultural soil.
- Recycles the waste material to ergonomically useful product in an environmentally friendly way.

The use of Bio NPK Biosolids would ;

- Increased crop yield
- Improved soil conditions – soil conservation & restoration.
- Reduced health risks to farmer associated with sludge.
- Reduced demand of water thus making this valuable resource available for irrigation.
- The nutrient rich sludge which otherwise is wastefully discarded can be gainfully recycled for economic gain by farmers.

Overall, the benefits outweigh the risks and financial costs in treating and utilizing the bio solids.

Conclusion:

Radiation Hygienised Biosolids with Bio NPK provides safe and effective manure as a supplement to chemical fertilizers. It improves soil fertility and helps in recycling of Biosolids in an economic and environmentally friendly manner. Due to large variations in pollutant load, USEPA standards for Exceptional Quality Sludge could be gainfully followed by FCO and other authorities for treated sewage sludge use in agricultural applications. The use of treated sewage sludge benefits all including the farmers, health & environment. FCO should include treated biosolids for use as manure by farmers for agronomical benefits and indirectly helping environment. Use of treated and limited sludge use outweighs the benefits over risks and financial costs involved.

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Installation Damage of Geosynthetics

The geosynthetics are prone to some amount of damage during their installation. To assess the quantity of the installation damage, a standard method was initially developed by Watts and Brady of the Transport Research Laboratory in the United Kingdom. The procedure has also discussed in the ASTM D 5818 with similar requirements. We are at BTRA doing the test following same ASTM D 5818 method followed by respective tensile strength. For the time being we are using the construction site for the sample preparation. If customer will agree, BTRA will collect the sample from site after standard procedure and provide the report.

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