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Abstract | This research was initiated as an investigation about the afterlife of the prodigious amount of rejections witnessed post firing process at ceramic industries in India. To further expand the optimization of application development of this waste an inspiration was drawn from Asian culture where a natural way of life was designed to re-use and recycle materials for longevity. The key idea about recycling fired ceramics was to be able to reuse the waste for multiple production cycles instead of using it once and in turn generating more untreatable waste at the end of its lifecycle. To realize this vision recycling was carried out as a mono-material making it a 100% recyclable material. This paper, along with offering corporeal solution to the material crisis intends to offer an initial nudge to open up conversations about waste pertaining to materials other than plastic and water. Thus making a direct positive impact under SDG12.

KEYWORDS| CIRCULAR ECONOMY, CERAMIC RECYCLING, CLOSED-LOOP MANUFACTURING, CIRCULAR DESIGN, POST INDUSTRIAL WASTE, CONSCIOUS CONSUMERISM, SDG12

1. Need Assessment

According to a report by Market Research Store: “In terms of volume, the global ceramic tiles market stood at 13.0 billion square meters in 2014.” (2015). Another report[1] states: “each year approximately 250,000 tons of tiles are worn out, while 100 million tiles are used for repairs.” (2012). Just one sanitaryware cluster in India carries out production using around 7.2 Lakh tons of clay per year out of which 21,600 tons of fired pieces go waste due to manufacturing defects. Multiply this by 5 decades of production at this cluster.

Notably, after life of ceramic is more daunting than plastic. Plastic can be recycled number of times. Even though it takes hundreds of years for plastic to decompose, it does decompose[2] (not to forget bio-plastics); while ceramic remains for even longer times or perhaps forever. That’s what archeology has shown us[3]. Though ceramic does not affect ecology adversely but just lays there like a dead weight, unutilised. Yet it has not been recycled, only dumped from one place to another.

I thought of utilizing this fired stoneware waste in maximum amount to make value added products out of it. The forming process for such a material and more importantly the binding agent to be used to give form to this dry inert waste was to be determined through thoughtful experimentation. The major challenge was to find out a binding agent that would help in congealing this waste for number of cycles instead of solidifying it once and adding to the waste after its life cycle. The strength, applicability, availability, economics were some of the parameters to be kept in mind while looking for the binder.

2. Aligning With Culture

Every child since their school days is told about recycling of waste. But unfortunately in India, like other aspects of schooling, recycling also remains as a theory and fails to be a way of life. What we do not really discern is that recycling is the last option that we have recognized to avoid letting objects go for landfill. Recycling uses up precious energy to transport refuse material to the processing unit, the processing itself adds up to major consumption of energy.

We must always reduce the waste we generate by optimal use of resources and objects for our daily routine. The next step is to reuse the resources by keeping them in circulation, where it is passed on from one person who doesn’t need it anymore to another who is or will be in need for it in the near future. This sharing of resources aids to the longevity of materials. Sharing of resources hold a similar importance, which also builds a strong community bond against the current norm of use-and-throw where we hardly get to observe any interaction among the community members.

Once we have reduced our refusal pattern and also reused resources to the last possible point then it is time to recycle the material for its further processing and value addition.

However, our roots into Asian backdrop, where recycling and reusing are not just the terms introduced in context to the current environmental concerns but continue to be a critical aspect of our socio-cultural-economic fabric; this awareness and life experience brings in meaningful contribution to our endeavors.

3. Fired Waste at Industries

Once the pieces are fired and out of kiln the material becomes abrasive and permanent. Nothing can be done to it through biological or chemical processes. This large amount of inert waste stays lying on the surface of the planet forever[4]. The rejects could be in the form of deformities, breakages, cracks or glaze defects.

The pieces with major defects are a direct waste; however, the ones with minor defects are fixed using external bonding agents and sold to smaller traders which are bought by low income group consumers.

The sanitaryware manufacturing cluster at Thangadh, state of Gujarat, India earlier used to throw away their fired rejects on either side of the streets. It is said that 10 years ago a trail of broken sanitarywares could be witnessed on roadsides 10km before reaching the cluster. Though with the pollution control board of India getting stricter year by year presently no factory is allowed to throw their waste on the roadside and are forced to confine it to their premises.

Figure 1. Fraction of fired ceramic waste at industries in Thangadh, Gujarat, India

4. Ceramic Studio – A Green Practise?

Every material has a waste counterpart and as production scales up so does the volume of this waste. Utilizing this waste becomes utmost important to keep a check on the environmental impacts of our production activities.

> "As a ceramic practitioner, the potentially negative environmental impact of our practise has steadily risen in the consciousness of many as environmental responsibility has moved up the social and political agenda.
>
> Ceramics is inherently brown (as in not green). We mine materials from the earth, and often not in what everyone would call a sustainable manner. Ceramics will never be what most would consider a green practice, but that is all the more reason to mitigate what we do in areas that may or may not directly impact a studio practice.
>
> The making of any ceramic artifact, be it functional, sculptural or architectural, inevitably involves detrimental environmental impacts – the inevitable generation of waste through making.
>
> No governmental agency will likely attempt to regulate studios' carbon footprint as an industry, because they simply don't produce enough of a footprint in one place, but that is a pretty bad reason to do nothing." (Harrison, 2013)

5. Material Testing

To start testing the material, fired ceramic powder (grog), for various possibilities to develop applications for it; it was necessary to understand the properties offered by grog. This helps us to understand the core reason for using the material purposefully and not just as an aggregate which after one lifecycle will contribute to even more waste generation.

Following were the properties identified with the material:

- Heat insulation (low conductivity)
  Copper: $6x10^{7}$ S/m
  Ceramic: 10^{-3} S/m to 10^{-5} S/m
  Air: 10^{-15} S/m
- Electric insulation
- Fire resistance
- Density
  MDF: 600 Kg/m^3
  Ceramic: 2130 Kg/m^3
  Steel: 8030 Kg/m^3
  Cast iron: 7207 Kg/m^3
- Weather proof/corrosion resistance (chemically inert)
- Abrasive

- Semi to non-porous

Advantages of using pulverized fired ceramic waste (now on mentioned as ‘grog’), offers above mentioned properties without fragility. i.e. It is an insulator without being prone to breakage.

5.1 Binder

Theoretically most of the above mentioned applications are possible as long as we know which appropriate binder to be used. After reading about various binding agents like resin, concrete, plastics and interacting with material experts it was realized that using clay itself is the best solution to move ahead with. Recurring utilization of material is a priority and adding any foreign binder to the waste will make it difficult to separate at the end of its lifecycle to recycle it even further. Hence, clay was identified as an optimum solution which adheres to closed-loop manufacturing for many more cycles.

5.2 Jigger Jolly Tests

As the most convenient method to develop tableware in ceramic industry is through jigger jolly, a series of tests were carried out to check the workability of the material in various compositions with the clay body.

- The following samples were tested in a jigger: 60/40, 50/50, 40/60, 30/70, 20/80, 10/90
  Where numerator is the portion of clay and denominator is the portion of grog. ‘clay/grog’

Observations:

- 60/40 showed results equivalent to virgin material
- All other compositions had rough surface with creasing on the outside
- The pieces while drying in the green stage developed cracks
- Foot of the pieces did not receive enough pressure in the jiggering process, hence, sustained creases
- While cutting the excess material at the rim, the material chipped off unpredictably
- Sometimes the moulds did not release the pieces even after an hour since jiggering

Reasons:

- The plaster moulds might have quickly absorbed moisture on the outer surface, hence causing creasing
- As the outer surface was already relatively dryer than the inner surface the difference may have caused the pieces to develop cracks while drying

- Due to low plasticity rendered by high grog content, the foot may not have receive enough pressure
- As the tests were carried out using old plaster moulds the capacity of the moulds to absorb moisture might have saturated, hence, it did not release the clay
- Due to quicker drying and low binding the material may be getting chipped off while trimming at the rim

Figure 2. Creases on the outer wall may be due to low plasticity of the material. Cracks on the inner wall may be due to uneven drying rate of outer and inner walls.

5.3 Glazing

These pieces were finished and cracks were fixed. Once bisque, they were glazed and fired at 1220 °C.

Among all the pieces only 60/40 survived while rest others developed cracks and were warped to varying extent.

5.4 Weight/Density

Since these were the very first high fired glazed pieces developed using varying percentage of grog, each piece was weighed to understand the effect of grog in a body. Interesting results were observed. With the increase in the percentage of grog in the body also increased the weight of the final piece.

This may have been possible due to the following reasons:

- Unlike clay, grog does not hold water content before firing.
  For example, once fired clay becomes porous due to loss of water content and becomes lighter. However the weight of grog remains the same before and after firing.
- With the shrinkage of clay body the same quantity of grog gets compressed to a smaller volume which may be increasing the density of the piece.

5.5 Slip Casting Tests

As shared by the people working in Thangadh, a small ceramic producing town located in the state of Gujarat, India, the industries here use just 2%-3% of grog in their slip owing to its high density. It was mentioned that if they used more percentage in their slip the grog might settle at the bottom causing hindrance to the production process and further loss.

After not being able to achieve desired results with jigger jolly method of ceramic production and hand building method, slip casting method as an additional experiment was tried and tested.

To try casting in varied shapes and sizes and to test the mixing of ingredients in a larger volume, a 12Kg batch of slip was prepared using industrial paint mixer. The slip was then casted into moulds of bowls, mugs, plate and cups.

This process required just 40% of water (by composition weight) and was an even mix as compared to earlier tests.

Since the moulds were not new the casting rate was around 10 minutes for open moulds, while around 15-20 minutes for a one piece mug (with pre-attached handle).

It was observed that due to the quick casting rate it was challenging to trim the excess clay on the mould at the rim. The casted clay became dry very soon and most of the time it chipped off unpredictably at the rim while trimming it.

During this test I learnt that the ideal density of a slip must be 170gm per 100ml.

- If 100ml weighs more than 170gm than add water
- If 100ml weighs less than 170gm then add clay

Since the slip dries quickly it was decided to keep the water content a little more than the required density. This extends the working time of clay at leather hard stage.

Figure 3. Clockwise from top left corner: Measuring the density of slip. Casting a bowl using 70/30 slip in a plaster mould. Casted bowls left for drying.

These casted pieces were then fired at various temperatures to know at what temperature does the 30/70 composition vitrify. The pieces were fired at the following four temperatures:

- 1200 °C – The pieces were over vitrified and warped. Their surface turned glossy as it crossed the vitrification temperature for the body.

- 1160 °C – The pieces were perfectly vitrified with a matt surface, low porosity and no warpage. The pieces exhibited an approximate shrinkage of 13% and porosity of 0.8%.
- 1140 °C & 1100 °C – The pieces were under fired and remained porous.

These pieces were then glazed, using dipping and spray technique, and fired at 1160 °C and thus were ready the first prototypes of “70% recycled ceramic tableware”.

Figure 4. Top: 30/70 unglazed pieces fired at 1160 °C. Bottom: 30/70 glazed pieces fired at 1160 °C

5.6 Basic Clay Tests

As the grog already contains clay body ingredients, it makes lesser sense to use clay body as a virgin material to bind grog together. We just need single clay that would act as a natural binder. This shall also bring down the production costs dramatically, as we do not need multiple ingredients to prepare a clay body and it also lowers the process costs.

Fire clay (also known as ‘Than’ clay) has good plasticity. It offers high strength in green state and also undergoes less warping during firing.

Two compositions were tested in jigger jolly. This time the moulds used were in good condition to avoid any confusion over the result based on the mould quality.

60/40 and 50/50 compositions were tested in a jigger with just fire clay as a binder. This, however, shared similar result to that of the jigger tests with S1 clay body. Creases and under-pressed foot were prevalent. Hence, the tests were consolidated with undesired outcome.

5.7 Slip Casting with Fire Clay

Since slip casting has shown promising result with previous tests, the same was taken ahead with basic clays. A couple of clays, individually and in combination, were tested to get an optimum result. This time tests were conducted keeping production in mind, where ease of processing and economics were major considerations. Aesthetics were expectedly similar to any other tests conducted previously.

Three compositions were tested using fire clay as a binder in the slip prepared for 50/50, 40/60, 30/70.

- 30/70 - Observations
  - Dries quickly
  - Chips off unpredictably while trimming at the rim
- 40/60 – Observations
  - Manageable rate of drying
  - Trimming hardly causes chipping if performed at the appropriate time
  - Faster casting rate for more productivity
- 50/50 – Observations
  - Similar to 40/60 composition

Figure 5. Final product samples made using 40/60 Fire Clay composition.

6. Market Testing

At every stage of experiments, prototypes were made and shared with people to identify the requirements by the users and the actual target audience. The various platforms gave an opportunity to interact with people, know their preferences in terms of forms, finish, volume and costing, among other factors.

A major observation to be made was, if people are actually interested in recycled ceramic tableware. Fortunately, majority of the population is intrigued by the idea and have been inquiring about the availability of these pieces for purchase.

Majority of the people I could interact with had one common taste. They all preferred matt finish wares over glossy ones. The younger crowd was mostly interested in mugs while the older ones asked for cups, glasses and plates.

Initially, the prototypes displayed at this venue were made of 30/70 S1 composition, hence, some had uneven edges to them due to chipping. The rim was round and soft but not perfectly circular. People did not really mention the uneven edges as a defect; some of them appreciated the unevenness for its essence of handmade and one-of-a kind recycled wares. The idea of Wabi Sabi surfaced as a common interest. This may be due to the shared cultural essence of Asian aesthetic perception.

People who owned gifting business showed interest for institutional sales. Interior designers showed similar interest. One among them was a person who runs a 3D printing business and was interested in exploring the use of recycled ceramics as a material for 3D printing.

Overall, the major learning was that there is an audience for these products who is willing to avidly use products that cause less harm to the environment. The next step would be to develop a broad and relevant category of wares for people to choose from.

7. User Persona

Based on discussions with people from varied backgrounds and age groups the following personality traits have been identified to be best suited as target audience for 'Recycled Ceramic Tableware'.

- Having raised awareness about negative ecological effects of material consumption
- Interested in contributing towards reducing carbon footprint
- Enthusiast about or already practising eco-friendly living through low waste generation
- Empathetic towards judicial use of resources
- Attempting to or already using re-usable containers instead of single use ones
- Willingness to spend on products that connect to their lifestyle instead of buying fancy pieces
- Financially independent from higher middle-class and higher income groups. Mostly aged 25 and above.

Keeping these attributes in mind the form and branding shall be developed that caters to the niche choices of these individuals who prefer to buy products that address their exclusive taste for unique products. An experience that gives them the essence of using a fine industrial product yet having a handmade touch to it.

8. Technically Sound Material

This newly developed material was tested by CGCRI (Central Glass and Ceramic Research Institute), government of India. The material has been reported to be 35% stronger than traditional ceramics.

Usually in a studio setup in India the firing temperature for stoneware pieces goes up to 1220 °C. While this recycled material can be vitrified at a temperature of 1120 °C. These tests were conducted after the material showed positive results at 1160 °C. Thus reducing energy consumption yet giving better results. Essentially, doing more and better with less.

9. Benefits of 40/60 Fire Clay Body

Some of the ecological advantages of this material include:

- Reduces mining for natural resources by 60%-70%
- Utilization and productive disposing of waste lying around since decades
- Uses lesser energy/fuel during firing

Some of the economical advantages of this material include:

- Can be manufactured using existing technology and processes, hence, no upfront investment needed to adopt to using recycled ceramics as a manufacturing material
- Quick casting rate increases productivity
- Lower vitrification temperature reduces firing costs
- Aesthetics at par with traditional wares, hence, holds even more value by utilizing waste yet offering high quality product

Some of the technical advantages of this material include:

- Can be moulded in products through casting, hence, offering endless possibilities with 3D forms
- Higher material density
- 35% stronger than traditional ceramics
- Fuses well with existing glazes
- 100% recyclable for closed-loop manufacturing process, adhering to circular economy policies

Other than the technical benefits, a major ecological advantage of using this material is that we reduce mining for fresh resources by 60%. This in itself is a major move against the existing rate of using grog by various Indian industries at 2%-10%.

While the usual perception about recycled products is such that they look different and may be of lower quality, this material defies all these perceptions by achieving aesthetics at par with traditional ceramic wares. Visually it stands as a traditionally developed product but on the inside it holds a lot of value for all the stakeholders.

During the firing process if pieces develop cracks or other kinds of rejects this material provides such pieces an opportunity to be used again as a raw material, hence, adhering to the principles of circular economy through closed-loop manufacturing. Thus, directly supporting SDG-12 – ‘Responsible Consumption and Production’.

10. Reflection

In the current times it is very easy to bypass patents and others replicating your methodology and ideas without your consent. Hence, how much ever important it might be to protect one's IP through such legal registration it is equally important to put our creation out there in the public eye to realize the actual worth and acceptance of the idea by the common people who are eventually going to be the real customers of future. The overwhelming response that I have received from strangers is truly heart-warming. Their effort to get in touch with me and genuine interest in buying these products has swept away all the scepticism that aroused during the process due to uncertainty. Such public validation is a valuable asset to move ahead with courage for any endeavour that dares to try something new in an ecosystem where the idea never existed in the past.

11. Future Prospects

I have started with making tableware as in ceramic industry tableware is the only product that a consumer chooses to buy directly. And we use tableware to host our guests where these products may act as talk trigger and would hopefully start a conversation about being mindful of the materials and products we choose to buy, to align towards a more nature-friendly living.

I will then move towards developing architectural applications for this material. Use of this may also aid for the development of Green Buildings. Being a stronger, durable material we can look forward to developing outdoor garden furniture, as ceramics is an insulator and is easy to clean in order to maintain hygienic conditions. Being weather proof make its an apt choice for outdoor use.

Among various benefits of this project one major benefit is that we can reuse the ceramic post-industrial waste in high proportion without the need for an upgraded technology. This innovation can be prastised in the existing, both new and conventional/traditional, ways of manufacturing. This dramatically reduces the upfront cost needed for adapting to a greener solution. We can create an optimized large scale impact by implementing this solution in almost all the existing ceramic industrial set-ups.

Though, it doesn't mean that this innovation cannot shake hands with evolving technology. With further R&D we may be able to use this material for 3D printing ceramics and a whole lot more. This innovation optimizes the existing processes to make current manufacturing practices efficient rather than making existing methodologies obsolete.

Creating and promoting a new culture of conscious consumerism which is resilient towards changing environmental conditions and its impact.

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Shashank Nimkar is a multi-disciplinary designer with an avid interest in addressing social challenges through research and design thinking. He has been recognized as a circular design/economy pioneer by the Ellen MacArthur foundation for his work on ‘recycled ceramics’.