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PRATICHE TRADIZIONALI E TECNOLOGIE INNOVATIVE PER L'END OF WASTE

a cura di
Adolfo F. L. Baratta

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Reuse of salt waste in 3D printing: Case study

*Salt waste, Printing mortar, Printability,
Case Study, 3D printing*

Summary

Salt waste from desalination plants and potash mining industry already presents an environmental problem. Salt (NaCl) in combination with other materials shows promising mechanical and physical properties and has already been used as a building material in the past.

This experimental study focuses on using salt in 3D printing technology to improve the resource efficiency of both the building material and construction process (speed, cost, accessibility).

To analyze the printability of salt mortars, four different material groups (SS- salt and starch, SC – salt and clay, CS – salt and concrete, SG – salt and gypsum) each prepared in six different mixes were evaluated according to a range requirements (pumpability, printed shape maintenance before it hardens, proper binding time around 30 minutes, possibility to build another layer and surfaces).

The most promising printing mortar was selected for a 3D printing process with a clay printer (Potter Bot Micro 10) for more complex print objects.

The SC printing mortar performed the best in terms of printability requirements, stayed stable after the hardening period and also preserved the complex printing shape. However, SC print objects showed high efflorescence on the surface and connection problems between printing layers on some positions.

In the future special attention should be given to the further development of the printing mortars. In general, experimental results demonstrate that salt printing mortars provide a promising method for 3D printing.

Introduction

The world population and with it, the use of natural resources are growing. Water shortages affect around 3.6 billion people [United Nations Secretariat, 2002]. One solution to this water shortage is to desalinate seawater. Around 16,000 desalination plants are already working around the world that extract fresh water from seawater and discharge 142 million cubic metres of hypersaline brine (ca. 8,45 million m3 salt a day) into the sea [Jones, Qadir, van Vliet, Smakhtin, & Kang, 2019].

The United Arab Emirates alone are responsible for the production around 120 million tons of salt per year. Another huge amount of salt waste (NaCl) is created in potash production [Rauche, 2015]. Potash is used as a fertilizer in extensive agriculture and the byproduct of its production (mostly salt) is disposed into nature (Figure 1). The negative environmental impacts due to the increased salt content in the seas, rivers and earth have been already acknowledged in literature [Hoepner & Lattemann, 2003; Musfique & Rifat, 2012; Palomar & J. Losada, 2011].

The use of salt in building construction is usually associated with possible damage rather than in relation to its value. Salt (NaCl) is porous at room temperature, dissolves in water and stores thermal energy and moisture [Bauer, Song, & Sanborn, 2019; Feldman, 2003; Ferguson, 1922; Gevantman, 1981; Sayem Zafar, 2015]. Moreover, salt caves and salt rooms are acknowledged as a therapy against sleep disorders, depression and respiratory diseases. In the past salt was used in combination with other materials (clay, concrete, starch) as a building material, or was cut and used in block from nearby salt seas or underground mines [Petruccioli & Montalbano, 2011; Rovero, Tonietti, Fratini, & Rescic, 2009].

Since a direct application of salt waste is not possible (salt is too porous), combinations with binders and new technological processes such as 3D printing (additive manufacturing) shows further potential.

3D printing is a technology that allows for a higher complexity of design, more automatization and lower production costs in the construction of one-offs and small series [Blok, Longana, Yu, & Woods, 2018; Zhang, Wang, Dong, Yu, & Han, 2019]. Various technical processes such as binder jetting [Gonzalez, Mireles, Lin, & Wicker, 2016] and paste extrusion [Patel, Blackburn, & Wilson, 2017], have already been described in the literature on 3D-printing with salt [Ganter, 2011; Geboers, 2015; Rael & San Fratello, 2018; Yuan, Ding, & Wen, 2019]. However, only two salt mixtures have been used and documented in the literature on 3D printing [Ganter, 2011; Rael & San Fratello, 2018].
Therefore, in an attempt to use salt waste to increase the resource efficiency of the building materials and optimize the constructional flow (cost, time), other mixes for salt (NaCl) mortars in 3D printing technology were investigated and carried out at the Chair of Building Construction and Material Science EBB, TUM.

Figure 1. Potash tailings stack Kali monutain at Heringen, Germany [Photo: Vesna Pungercar].

Methods and materials

This experimental research was motivated by increasing trends to use waste materials in building construction. The methodology analyses the potential and limitation of salt materials used as printing mortars in the 3D printing. The main part of the investigation was to identify potential binders in literature, to define the mixing ratio of salt (rock salt) and binder for printing and to reveal the most appropriate salt mortar for printing (Figure 2).

Different salt mixtures were first injected by hand onto a Plexiglas plate in a circular form of up to three layers, hardened at room temperature and evaluated after one to three days. These first prototypes were used to study the mixing ratio of salt and binder and the quality of the printed objects were studied (pumpability, printed shape maintenance, proper binding time, possibility to build up another layer and surface smoothness). The most promising mixture was selected for 3D printing with a clay printer (Potter Bot Micro 10) to print more complex designs.

The materials used during the study were: salt (NaCl), sand (0,1-0,4mm grain), cement, gypsum (hemihydrate), water, starch (Maltodextrin), clay and water. They were listed in the Table 1 to show dif-

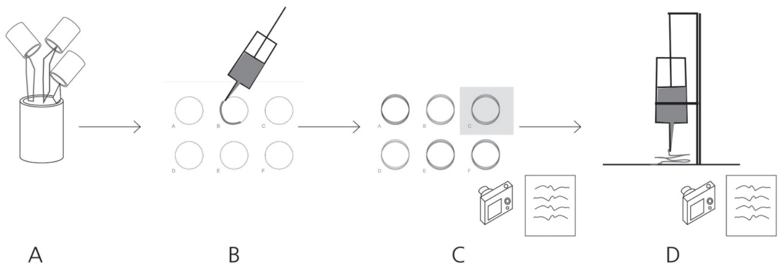


Figure 2. Method for the experimental study.A - mixing materials, B – experimental printing with hand injection, C – selection of the most appropriate printing salt mortal, D – printing the selected mortal with 3D-print [Original from authors].

ferences between mortars. The material mixtures were divided into 4 different groups and named after composition of salt and binder: SS (salt and starch), SC (salt and clay), CS (salt and concrete) and SG (salt and gypsum).
Each material group had six mixes (recipes from A to F) with different mixing ratio of salt, binder and water. Recipe A in 4 groups was always the initial mix based on the literature review. The following recipes (B-F) were continuously adjusted due to observation of the previous recipe. For example: the recipe A of mortar SC was too liquid, so in the recipe B the water amount was decreased. Resource efficiency of each mortar was shown with the salt and binder ratios.

Results and discussion

It was observed that the binders significantly changed the properties of porous salt. The presence of starch (SS) greatly increased the viscosity of the mortar so that it became impossible to create the shape. The main disadvantages in the SG group were their short binding and hardening times. Materials from the CS group were not plastic enough and took too long to dry.
The SC group was very easy to pump; the shape of the printing prototype was easily maintained; binding time was short; and it was easy to build another layer. However, the surface of fresh or hardened mortar changed as it hardened and high levels of efflorescence occurred on the surface.
Quality of the mortars was measured with printability requirements and a basic scale of 1 to 3. The scale 1 represents a maximum score with a good performance, 2 a middle score with an average performance and 3 a minimum score with a bad performance (Table 2). The mortar with the highest number of the scale 1 is the best-evaluated mortar. At the end of this investigation, the printing salt mortar from group SC (recipe D) was selected for more complex 3D printing with the clay printer.

Group	Recipe	Ratio salt/binder	Salt [g]	Clay [g]	Fresh water [g]	Sand [g]	Cement [g]	Gypsum [g]	Starch [g]
SS	A	**88:12**	**352**	-	**10**	-	-	-	**48**
	B	50:50	200	-	100	-	-	-	200
	C	61,5:38,5	200	-	40	-	-	-	125
	D	21:79	80	-	40	-	-	-	300
	E	46:54	90	-	40	-	-	-	105
	F	30:70	45	-	40	-	-	-	105
SC	A	70:30	280	**120**	100	-	-	-	-
	B	70:30	280	**120**	60	-	-	-	-
	C	80:20	320	**80**	60	-	-	-	-
	D	60:40	240	**160**	60	-	-	-	-
	E	65:35	260	**140**	40	-	-	-	-
	F	65:35	260	**140**	60	-	-	-	-
CS	A	50:50	600	-	320	**480**	**230**	-	-
	B	60:40	480	-	190	**576**	**144**	-	
	C	60:40	480	-	190	**576**	**144**	-	-
	D	60:40	320	-	104	**384**	**96**	-	-
	E	70:30	240	-	104	**448**	**112**	-	-
	F	80:20	160	-	104	**512**	**128**	-	-
SG	A	50:50	50	-	20	-	-	**50**	-
	B	60:40	60	-	15	-	-	**40**	-
	C	60:40	60	-	18	-	-	**40**	-
	D	50:50	50	-	18	-	-	**50**	-
	E	70:30	70	-	16	-	-	**30**	-
	F	40:60	40	-	19	-	-	**60**	-

Table 1. Mortar printing mixtures [Original from authors].

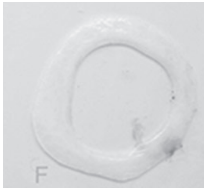
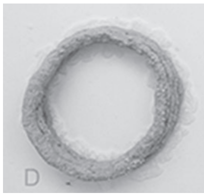
Group	Recipe	Pumpability	Printed shape maintenance	Proper binding time	Possibility to build another layer	Surfaces	Photo of the best mix
SS	A	3	3	3	3	1	
	B	3	3	3	3	1	
	C	3	3	3	3	1	
	D	2	3	3	3	1	
	E	2	2	3	3	1	
	F	2	2	2	3	1	
SC	A	2	3	2	3	2	
	B	1	2	1	1	1	
	C	2	1	1	1	2	
	D	1	1	1	1	1	
	E	3	3	1	3	3	
	F	1	2	1	2	2	
CS	A	1	2	3	3	2	
	B	2	3	3	3	3	
	C	2	3	3	3	2	
	D	2	2	3	3	2	
	E	1	2	2	3	2	
	F	1	2	2	2	1	
SG	A	3	3	3	3	3	
	B	3	3	2	3	3	
	C	2	3	3	3	3	
	D	3	3	3	3	3	
	E	3	3	3	3	3	
	F	1	2	3	2	2	
Legend: 1 -good, 2-average, 3-bad							

Table 1. Printability requirements for mortars [Original from authors].

The SC mortar also resulted in good printed quality of complex prototype objects using the clay printer.
Most of the time, it was possible to press fresh SC mortar through a 5mm nozzle while preserving the printing shape.
However, in some cases, the high porosity of the printing mortar decreased its fluidity, causing a slower flow and the poorer connection of the printed layers.
After the hardening period, the prototypes did not shrink significantly but stayed stable.

Conclusion

This paper focuses for the first time on using salt waste as a component of building materials for 3D-printing technology.

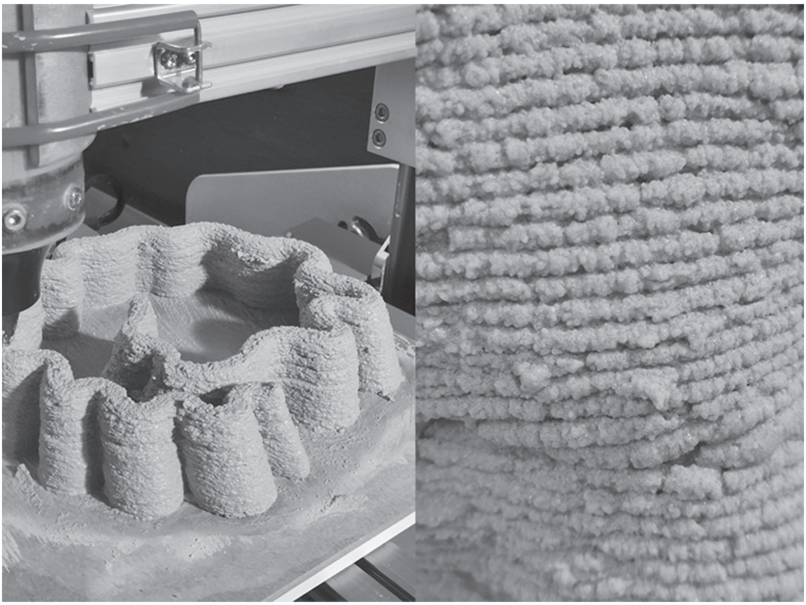


Figure 3. 3D print prototype with SC(left). Connection of printed layers of SC mortar (right) [Original from authors].

Results shows that salt with clay best met printability requirements of all printing mortars. However, other salt printing mortars should be further investigated with other additives (superplasticizer, restrainer or viscosity modifier) and 3D printers.
We believe that using salt with 3D-printing technology increases the resource and building process efficiency and will acquire further significance in the field of building construction.

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