Preprint 16-150

MINE STOPPING CONSTRUCTION AND LEAKAGE

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ABSTRACT

The “Reiche Zeche” mine in Freiberg, Germany, a 600-year-old lead-zinc-silver mine with extensive open mine workings, experiences severe ventilation losses due to leakage. Much air leaks into abandoned workings, decreasing the airflow available to active working areas. Usually, this leakage occurs in remote areas that lack transportation infrastructure like roadways or rail, making it difficult to haul construction materials to the sites to erect passive ventilation controls such as stoppings, regulators and seals. Transportation distances make it impractical to hand carry traditional construction materials, such as bricks and concrete. Alternative materials, such as brattice, foaming polymers, concrete canvas, and some innovative ventilation control designs have been investigated for this purpose. The suitability of the materials investigated depends on many factors including the pressure it can withstand, the ease of transportation, and workability. Impacts of mine water must be considered, as the Reiche Zeche is below drainage and experiences significant inflow of water. Researchers must consider the effects water inundation as well as how the stopping construction material reacts to being exposed to acidic mine water.

INTRODUCTION

Problem Statement

Mining in the area around Freiberg, Germany began in the 12th century. The mine is used for research, mining engineering education, tourism and air conditioning for a local hospital. The first records of mining in the Reiche Zeche are from around 1384. Due to the strength and competency of the host rock, many of the oldest workings still stand and remain open today, although they may not be accessible. Reiche Zeche also connects to several other, closed mines in the area that are largely unmapped. This allows air to leak into neighboring mines, reducing the air available to ventilate to the working areas of Reiche Zeche. In order to improve ventilation efficiency, it is necessary to control the ventilation and reduce leakage by constructing seals, stoppings and regulators.

A challenge with building traditional seals and stoppings in the Reiche Zeche is that the old workings lack transportation pathways or rails. Also, the lack of compressed air, water or electricity makes it difficult to operate power tools and drills. This means that construction materials must be hand carried – some over distances of several kilometers. Figure 1 shows a typical drift in the Reiche Zeche.

Researchers investigated using lighter, more easily transportable materials including concrete canvas, expanding polyurethane and polyurea foams, and brattice. The applicability and utility of these materials depends on a variety of factors including the ventilation air pressure, chemical resistance to acidic and mineral-laden mine waters, ease of transport, and ease of construction. Stoppings and seals must be substantially constructed so that they remain tight and do not require maintenance. It is also important to consider the toxicity of the construction materials in case of a mine fire.

Figure 1. Typical airway in Reiche Zeche.

PASSIVE VENTILATION CONTROLS

If an airway needs to be permanently blocked off from both people and air, a seal should be constructed. For temporary or permanent separation of airways, a stopping is suitable. Mandoors or airlocks can be added if people need to pass through. The stoppings and seals must be designed to withstand the ventilation air pressure. The Reiche Zeche uses a blowing ventilation system with a fan in the “Alte Elisabeth” shaft which runs at a relatively low pressure of about 500 Pa. Pomeroy [1] created a numerical model of the mine ventilation system using VentSim software. This model has since been updated and improved and can be used to evaluate the effectiveness of new ventilation controls.

Following is a discussion of different stopping designs which may be practical for in the Reiche Zeche Mine.

Single Wall Stoppings. Single wall stoppings can be made out of brattice, masonry, concrete, or backfill-based, light-weight concrete [2]. The engineering design depends on the pressure differential. In low pressure cases, brattice alone may be sufficient while concrete is required for higher pressures. Due to the odd shape and uneven walls, thin concrete stoppings often start to leak as they age and deteriorate.

To regulate air flow, a fixed or variable regulator is required. Fixed regulators are built by leaving an appropriately-sized hole in the stopping, while for adjustable regulators, a sliding metal door or louver must be built-in. In this case, or if a door or airlock is required, a more substantial stopping design is required. Figure 2 shows a concrete-and-brick stopping with a door and a fixed regulator. The amount of time and the number of people involved in constructing these stoppings depends on the material used and the location of the construction site. At the Reiche Zeche, it may take a crew several days to build a remote masonry stopping, while it may take two miners only a few hours to construct a brattice stopping.

Figure 2. Concrete and brick stopping with steel door and a fixed regulator on the left side.

Double Wall Design for Seals. More substantial stoppings can be built with double walls. Watson [3], [4] describes a double wall design with a polymer fill material between them. The walls can be masonry, cinderblock, or foam blocks with a polymer sealant. The double wall design is effective for the construction of airtight seals but the construction is too labor-intensive [5]. A suitable alternative for Reiche Zeche may be erecting canvas walls with high density expanding polyurethane foam as the fill material. This seal can also be built strong enough to impound water in the event of a flood.

Stopping Construction Materials

Most existing stoppings in remote areas are built of wood which decays over time. Some concrete and brick stoppings exist in remote locations. In areas where transportation and construction infrastructure is available, concrete, shotcrete, and brick stoppings are common.

Concrete Impregnated Canvas. Concrete canvas[5] is a concrete impregnated fabric or cloth available in 5, 8, and 13 mm thickness and weighing, 6.5, 12.2, and 19 kg/m^2, respectively. Typical cross-sectional areas range between one and three square meters, facilitating transport. Once mounted in place, the canvas is wetted with water and hardens. The concrete canvas is resistant to water with pH values between 1 and 13 for extended time periods without losing its structural properties [5]. The canvas can be cut with hand tools and can be reshaped for up to two hours after being wetted [5]. Typically, the canvas is hung from wire mesh or a wood frame. Researchers expect that the canvas will be sufficiently strong to withstand ventilation pressures at Reiche Zeche although the manufacturer does not provide data. The canvas stopping is not expected to withstand the pressure of impounded water, so a relief valve must be installed if water may be impounded. The canvas material contains PVC plastics and may release noxious fumes if burned [5].

Expanding Polymer Foams. Polyurethane and polyurea (PU) foams are suitable because the reagents are easily transportable. The foam expands and creates a good seal to the mine walls. The PU materials may be sprayed or poured. Spraying may fill a greater volume, but requires a pump. Poured PU foam requires only a lightweight mold or frame but attains a smaller final volume. Landry et al. [6] point out that PU releases noxious fumes including hydrogen cyanide and carbon monoxide. Some mining authorities prohibit its use in underground mines for this reason. PU is waterproof and resists acidic mine waters as long as they contain less than 30% sulfuric acid [7]. It is less resistant to nitric acid. PU filled stoppings and seals can be designed to withstand air and water pressures if they are built as thick plug seals.

PVC Brattice. Brattice materials have been used for ventilation control purposes since the early 20th century [2]. Brattice curtains are hung from the back and may allow miners and vehicles to pass[8]. Today, fire resistant, PVC-laminated brattice [9] is still widely used and available in several thicknesses, heavier weights being suitable for higher air pressures. PVC is resistant to sulfuric, hydrochloric, and carbonic acids [10]. It is lighter than concrete canvas or any of the traditional construction materials, facilitating easy transportation. Construction of a brattice stopping involves fastening the brattice to a wood or wire frame within the airway. If necessary, PU foam may be used to seal any leaks around the edges.

CONSTRUCTION COST FOR STOPPINGS

The price of constructing a stopping includes material and labor costs. In 2015, an average labor cost for a miner in Germany is 38 €/hr [11]. 50% overhead will be added to the hourly rate to cover indirect labor cost. Material costs have been obtained from manufacturers and are summarized in Table 1 below. While some of these prices are dated, they remain useful for comparison. Brattice and wood are the least expensive materials for stopping construction. Stoppings made from brattice or wood also require less time and labor compared to concrete and brick stoppings. Concrete canvas is more expensive per unit area compared to the other materials but labor is similar to that for brattice.

Table 1. Materials Prices Summary.

Material	Material Detail	Price	Units	Source
Concrete Canvas	CC5	40	€/m^2	[5]
	CC8	50	€/m^2	[5]
Brattice				
(India Jute Fabric)	10.5 oz grade	0.59	*€/m^2	[12]
	14.0 oz grade	0.68	*€/m^2	[12]
	16.67 oz grade	0.88	*€/m^2	[12]
(Jute Plastic)		1.12	*€/m^2	[12]
(Nylon Plastic Brattice)	12 oz grade	1.53	*€/m^2	[12]
	18 oz grade	1.89	*€/m^2	[12]
	Heavy Duty	3.86	*€/m^2	[12]
(Plastic Brattice)	6 oz grade	0.47	*€/m^2	[12]
	15 oz grade	0.87	*€/m^2	[12]
(Cotton brattice cloth)		1.00	*€/m^2	[12]
(Bluefield Brattice Cloth)	11 to 13 oz grade	0.31	*€/m^2	[9]
Polyurethane	High Density Closed Cell foam	3	€/kg	[13]
Polyurea	High Density Closed Cell foam	10 to 11	€/kg	[13]
Concrete		70 to 80	€/m^3	[13]
Timber	Mine Grade No 1	724	*€/1000 bd m	[12]
	Mine Grade No 2	634	*€/1000 bd m	[12]
	Wedges (4x12 in)	0.14	*€/wedge	[12]
Wire Mesh	2.0 in squares, 12 gauge	0.99 to 1.09	*€/m^2	[12]

*These values were converted from US dollars to Euros (at 0.92€/$) and from imperial to metric units

**High density closed cell foam

Polyurethane and polyurea are both available as two component mixtures for pourable expanding foams. The price is listed in kilograms because the density of the foam will determine the volume it fills. The higher the density of the foam, the more PU will be needed. This makes it difficult to compare PU to other materials since the necessary density in the mine is determined by experimentation.

For the cost comparison, it is assumed that a stopping must be constructed 500, 1000, and 2000 meters away from the nearest transportation and construction infrastructure. The area of the airway is $1.5 m^2$. The cost of the stopping is calculated based on time and material costs. Transportation time, number of laborers, and construction time are estimated based on experience.

Table 2 lists the calculated material costs and construction labor hours for five different stopping designs. Independent of stopping design and construction materials, labor is by far the largest cost component. As the distance from infrastructure increases, the cost must increase as well. Table 3 lists calculated total construction costs considering manual transportation over distances of 500, 1,000 and 2,000 m. Transportation times for light materials were increased by a constant factor while times for heavier materials include additional rest times for the miners. Therefore, transport distance causes a greater increase in construction cost for heavier materials.

Table 2. Stopping Construction Details.

Material	Material Cost (€/1.5m^2)	Number of Laborers
Concrete Canvas CC5	60.00	3
Bluefield Brattice Cloth	0.50	2
Polyurethane*~	6.80	2
Concrete*	56.30	4
Timber**	6.00	2
*Assume the stopping is 0.5m thick		
**Assume each board is 20cm wide and the dimensions of the airway are 1mx1.5m		
~Assume expanded foam has a density of 3kg/m^3		

Table 3. Stopping Construction Costs.

Material	Transport Time (min)	Construction Time (hr)	Labor costs, €	Total Cost, €
500 meters transportation distance				
CC5	20	12	2,110	2,170
Bluefield Brattice Cloth	10	2	247	250
Polyurethane	10	6	703	710
Concrete	60	24	5,700	5,760
Timber	15	5	599	600
1000 Meters				
CC5	50	12	2,200	2,250
Bluefield Brattice Cloth	20	2	266	270
Polyurethane	20	6	720	730
Concrete	150	24	6,040	6,100
Timber	35	5	637	640
2000 meters				
CC5	120	12	2,400	2,500
Bluefield Brattice Cloth	40	2	300	305
Polyurethane	40	6	760	770
Concrete	375	24	6,900	6,950
Timber	82	5	725	730

CONCLUSIONS

It is possible and practical to construct ventilation controls with minimal leakage in remote areas with little transportation infrastructure in the Reiche Zeche mine. Proposed non-traditional construction materials include expanding polymer foams (polyurethane and polyurea), brattice, and concrete canvas. Concrete canvas is favored in wet parts of the mine with acidic conditions and areas close to the fan where ventilation pressures are higher. Polyurethanes can be used in areas with non-acidic conditions. Brattice is preferred for low pressure stoppings. Combinations of the materials could also be used to achieve minimal leakage. Labor costs make up the largest component of total construction cost and are significantly higher than material cost. Transportation, even to more distant construction sites, does not have much impact on total cost.

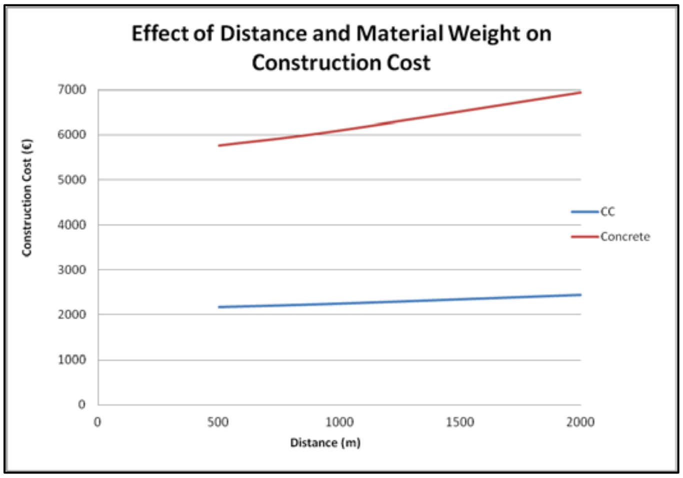

Figure 3. The effects of travel distance on the price of stopping construction.

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