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METHOD OF REMOVAL OF THE PLASTIC INSULATOR FROM WASTE CABLES BY PASSING THEM BETWEEN TWO ROTATING ROLLS THAT HAVE DIFFERENT SURFACE TEMPERATURES

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Abstract. Recycling of cable waste, especially the complete separation of metal and insulating material for reuse has always been a problem. Especially this problem is relevant for small enterprises because present processes to recover insulating material consists of many stages and requires expensive equipment. The processes usually involve multi-stage grinding of the cables into smaller pieces and separating them into metal and plastic fractions.

The problem can be solved by thermal methods based on the differences in coefficient of thermal expansion of the insulating material and conductor. By one of these methods the cable is passed between two rotating rolls, while surface of the one roll is heated below the melting temperature of thermoplastic insulator, surface of next roll stays cold. Thus the thermoplastic insulator of the cable breaks after the total impact of thermal deformation of insulator and metal conductor and softening of material of the insulator. Conductor remains undamaged and can be re-covered by new plastic insulating material layer. The experimental cable processing machine was designed and produced in the Laboratory of machines and technologies of the Vilnius Gediminas technical university, initial tests were performed. Such machine can be used by small cable manufacturing and waste management companies, electric devices repair and manufacturing workshops. Results of experimental research are presented as optimal peripheral speed of the rolls (or cable speed) versus diameter of the copper and aluminum conductor of the cable, when the temperature of the "hot" roll equals 160°C.

Keywords: waste cable, conductor, copper, aluminum, PVC insulator, roll, temperature.

1. Introduction

It is known that European waste management hierarchy is presented following (Staniškis *et al.* 2004; Osibanjo and Nnorom 2007):

- prevention or waste minimization
- materials recycling and reuse
- incineration with energy recovery
- incineration
- landfilling

It should be noticed that waste minimization to zero can't be achieved for many manufacturing processes at present, and only second principle in waste management hierarchy can be realized in many companies. It is not very difficult to recycle clean and homogeneous waste, but there can be serious problems with composite products made of different materials (for example, plastic mixed with metals, rubber, paper, other kinds of plastics, etc). In such a case, the waste separation (mostly multistage and high-priced) must be included in waste recovery process.

One such composite product is waste cables. The cable scrap can be produced during manufacturing process (for example, rejected for insulating material defects) and due to the end of life of cables (for example, during repair of electric devices and buildings). The most valuable component of the cable that must be recycled is non-ferrous metals (copper, aluminum). Next, thermoplastic insulator (like polyvinylchloride, polypropylene, and polyethylene) can be successfully granulated and reused in plastic molding machines. It is established that plastic insulated cable scrap contains 40–90 wt% of metals (Hitoshi 2000).

The main cable waste recovery problem is how to remove plastic insulator from metal conductor. In the past cables were recycled by simply burning them. The copper remained solid and could be collected after burning. Although burning cables was a simple and efficient technology, such thermal recycling is no longer allowed in many countries owing the release of heavy metals, dust, and harmful gases (hydrogen chloride, dioxins, etc) into the environment. In addition, it is not economic to recover only the metals, without considering the insulating material.

At present mechanical separation technologies are used. In general two technologies are being used to recycle cable scrap (Sijstermans 1997; Al-Salem *et al.* 2009):

- (cryogenic) shredding of cables
- stripping of cables

The room temperature shredding process involves a multistage grinding of cables into smaller pieces, separating them into metal and plastic fractions. The mostly used cable recovery equipment includes in that case the shredders, sieves, and various separators (for example, air table, electrostatic separator, floatex® density separator) used to separate metal from plastics and other materials (Tilmantine *et al.* 2009; Nemerow *et al.* 2009; Corbitt 1999).

In the cryogenic shredding process, cables are treated with liquid nitrogen to make the insulating material more brittle. After liberation, the metal particles are separated from the insulating particles by using the differences in density, conductive and magnetic properties. The cryogenic process did not find wider application due to the high cost of liquid nitrogen and cryogenic equipment (Sijstermans 1997).

Shredding process uses an excessive amount of energy for multistage grinding the cables into the smaller pieces. The shredding technology has a high capacity, so, it is mostly used in the big waste recycling companies. It is also is flexible, because more types of cable can be processed.

Shredding process results in some impregnation of the insulating material with fine metal particles. Impregnated metals are difficult to separate from insulating material, it is important for the reuse of insulating material to be absolutely metal-free.

In the stripping process the insulating material is being split and peeled of the conductor. By using stripping technology to process cable scrap, higher metal grades and recoveries can be achieved. The stripping machine is often manually fed, because it is necessary to straighten and precisely orient the cable in respect of the cutting rolls. Therefore stripping method has a low capacity. Cables with a small diameter cannot be stripped and must be shredded.

The insulator can be also removed from cable manually, but this process is not productive. Next, the insulator can be removed from conductor chemically with the help of solvents (Corbitt 1999), but in such a case solvents must be cleaned and utilized.

Further, the thermal methods can be used to remove the insulator from conductor. These methods are based on the differences in coefficient of thermal expansion of the insulation material and metals, with no need to grind the cable into small pieces to improve the liberation of metal. The cables can be cut into a suitable length and placed into a blender with hot water (Shein and Tsai 2000). By controlling the water temperature, blending speed and cutting length, complete separation can be achieved.

The thermal method has been proposed with no need to cut cables into the pieces. The single-core waste cable is placed between two rotating rolls (Fig. 1). Surface of the one roll is heated below the melting temperature of thermoplastic insulator and surface of second roll remains cold. The preparation of the cables consists only of rough straightening of the cables, method can be easily automated. It means that cable feeding and guiding device can be also used to avoid cutting the long cables into pieces. Different diameter, length and material single-core cables can be processed by this method. The metal conductor remains undamaged and free from insulating material; it can be re-covered by plastic insulator during further operations.

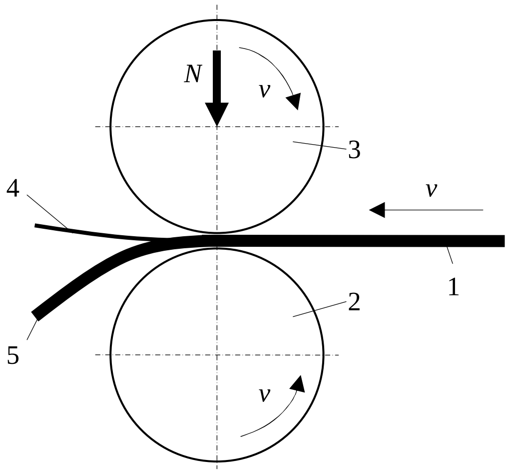

Fig 1. Scheme of removing the insulator from metal conductor: 1 – cable; 2 – “cold” roll; 3 – “hot” roll; 4 – metal core (conductor); 5 – plastic insulator; *v* – peripheral speed of the rolls and linear speed of the cable; *N* – load

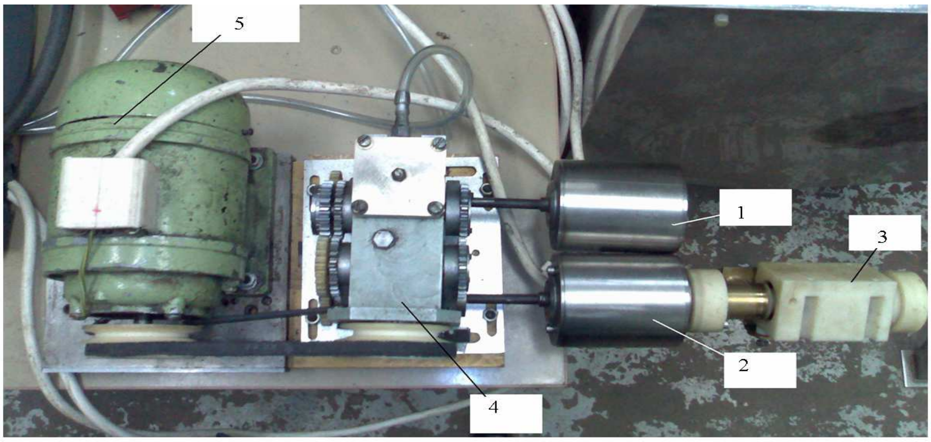

Fig 2. Experimental stand: 1 – “cold” roll; 2 – “hot” roll; 3 – current collector; 4 – reduction gear; 5 – electromotor

Table. Properties and composition of tested cables

Diameter of the cable, mm	Diameter of the conductor, mm	Thickness of insulating material (PVC) layer, mm	Metal, wt%		PVC, wt%	
			Al core	Cu core	Al core	Cu core
3	1.85	0.575	58	82	42	18
4.4	2.8	0.8	60.5	83.5	39.5	16.5
6.8	4.6	1.1	65.5	86.2	34.4	13.8

2. Experimental stand

The photo of experimental stand is presented in Fig. 2. Electromotor 5 rotates rolls 1 and 2 via belt transmission and reduction gear 4. Roll 1 rotates at the same speed as roll 2. Both the rolls have equal diameters 89 mm. Roll‘s 2 surface is heated below the insulating material melting temperature by means of current collector 3. Temperature of the surface of “hot” roll can be varied from room temperature to 250ºC. It is controlled by IR thermometer. The rolls are pressed one to another by pneumatic cylinder located inside the reduction gear 4. The rotational speed of the rollers (or cable speed) is varied by means of variable-frequency drive (not shown in Fig. 2) connected to electromotor 5. Both rolls made from special manganese stainless steel to reduce adhesion of insulating material to the surfaces of the rolls. Rotational speed of the rolls is measured by means of stroboscope (not shown in Fig. 2).

3. Object of research and experimental technique

Copper and aluminium single-core cables covered by single layer of polyvinylchloride (PVC) insulator were approved as object of experimental investigation. Parameters of the cables are presented in Table. Surface temperature of the “hot” roll during experiments was 160ºC while surface temperature of the “cold” roll equalled to room temperature (approx. 20ºC). Surface temperature of “hot” roll must be less than melting point of the material of insulator. It also must be high enough to soften the insulating material. It is recommended (Striška and Mokšin 2008) to calculate it by following formula:

$$T_{hr} = T_m - (50 - 60) \quad (1)$$

where T_{hr} is surface temperature of “hot” roll, ºC, T_m is melting temperature of cable insulating material, ºC (212ºC for PVC insulator (Макаров and Коптенармусов 2003)).

Before the experiments all tested cables were cut up into 2 m length pieces. These cable pieces were later placed between rotating rolls of experimental stand (Fig. 2). Quality of removal was controlled visually. If the incomplete separation of the insulating material was observed, the rotational speed of the rolls was reduced and additional test was performed. This procedure was repeated as long as complete removal of the insulator was observed, then the last rotational speed of the rolls was accepted as optimal speed for the given diameter of conductor of the cable. Next, the thicker cable was tested. Every test at optimal speed of the rolls was performed five times in order to minimize the influence of the random errors on results.

4. Results and discussion

The results of experiments are presented in Fig. 3 as average optimal peripheral speed of the rolls (or cable linear speed) versus diameter of the copper conductor of the single-core cable.

Fig. 3 illustrates that when the diameter of copper conductor of the cable increases from 1.85 to 4.6 mm optimal peripheral speed of the rolls required for complete removal of insulator decreases from 1.8 to 0.41 m/min (rotational speed of the rolls decreases from 6.5 to 1.5 rpm). When the diameter of aluminum conductor increases from 1.85 to 4.6 mm peripheral speed of the rolls decreases from 1.64 to 0.29 m/min (rotational speed of the rolls decreases from 5,9 to 0,9 rpm).

It is established that results of experiments can be approximated with following power functions:

$$v = 4.71d^{-1.62} \quad (2)$$

$$v = 5.27d^{-1.9} \quad (3)$$

where v is optimal peripheral speed of the rolls, m/min, d is the diameter of the conductor (core) of the cable, mm.

Equation (2) is valid for copper conductor cables and equation (3) is valid for aluminum conductor cables. Equations closely corresponds to results of experiments, theirs coefficients of determination 0.99 and 1 respectively.

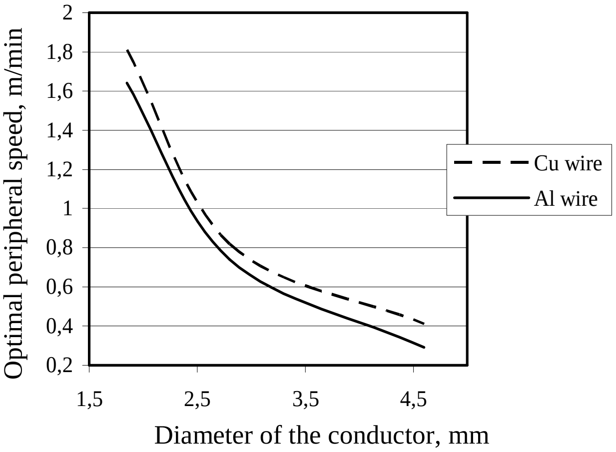

Fig 3. Optimal peripheral speed of the rolls as function of diameter of the conductor of single-core cable

As is evident from Fig.3, the insulating material can be removed from copper conductor cables at higher peripheral speed of the rolls as compared with aluminum conductor cables. When the 1.85 mm copper conductor cables are used the optimal speed of the cable increases 1.1 times as compared with aluminum conductor cables of the same conductor diameter. When 2.8 mm copper conductor cables are processed speed increases 1.1 times. 6.8 mm copper conductor cables show a 1.4-fold increase in speed.

The results can be explained by differences in coefficient of thermal expansion and thermal conductivity of the insulating material and conductor. When the one side of the cable is heated, the hot section at the contact place is lengthened according to well-known law:

$$\Delta L = \alpha_L L \Delta T \tag{4}$$

where ΔL is change in linear dimension, m, α_L is linear thermal expansion coefficient, 1/ºC, L is initial length, m, ΔT is change of temperature, ºC.

The linear thermal expansion coefficient of PVC (insulating material) is significantly larger than coefficients of copper or aluminum ($52 \cdot 10^{-6}$ 1/ºC (PVC, at 20ºC), $23 \cdot 10^{-6}$ 1/ºC (Al, at 20ºC), $17 \cdot 10^{-6}$ 1/ºC (Cu, at 20ºC)). This means that length of PVC section in the contact with hot roll zone increases more than length of conductor, which has lower temperature (Fig. 4) due to much less thermal conductivity of PVC layer. The difference between temperatures of the insulator near “hot” and “cold” rolls is significant (Fig. 4), section of PVC insulator near the “hot” roll has an increased temperature, opposite side remains colder, and the insulator starts to diverge from vertical. The temperature is more evenly distributed in the conductor (Fig. 4) due to bigger thermal conductivity, thus conductor is lengthened evenly and breaks through the soft PVC layer. Aluminum conductor diverges from vertical more than copper conductor due to less thermal conductivity and larger thermal expansion coefficient, the optimal speed is decreased.

The productivity diagram is presented in Fig. 5. Evaluating the density of conductor material, it can be stated that machine can liberate 0.0239 kg copper and 0.0073 kg aluminum per hour, while diameter of conductor of the cable equal to 1.85 mm. For 2.8 mm conductor cables these values are 0.0548 kg/h and 0.0166 kg/h respectively. For 4.6 mm conductor cables – 0.148 kg/h and 0.045 kg/h.

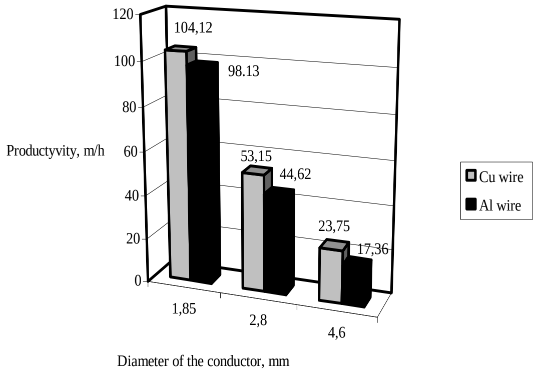

Fig 5. Productivity of removal of the insulator from the cables as function of diameter of conductor of single-core cable

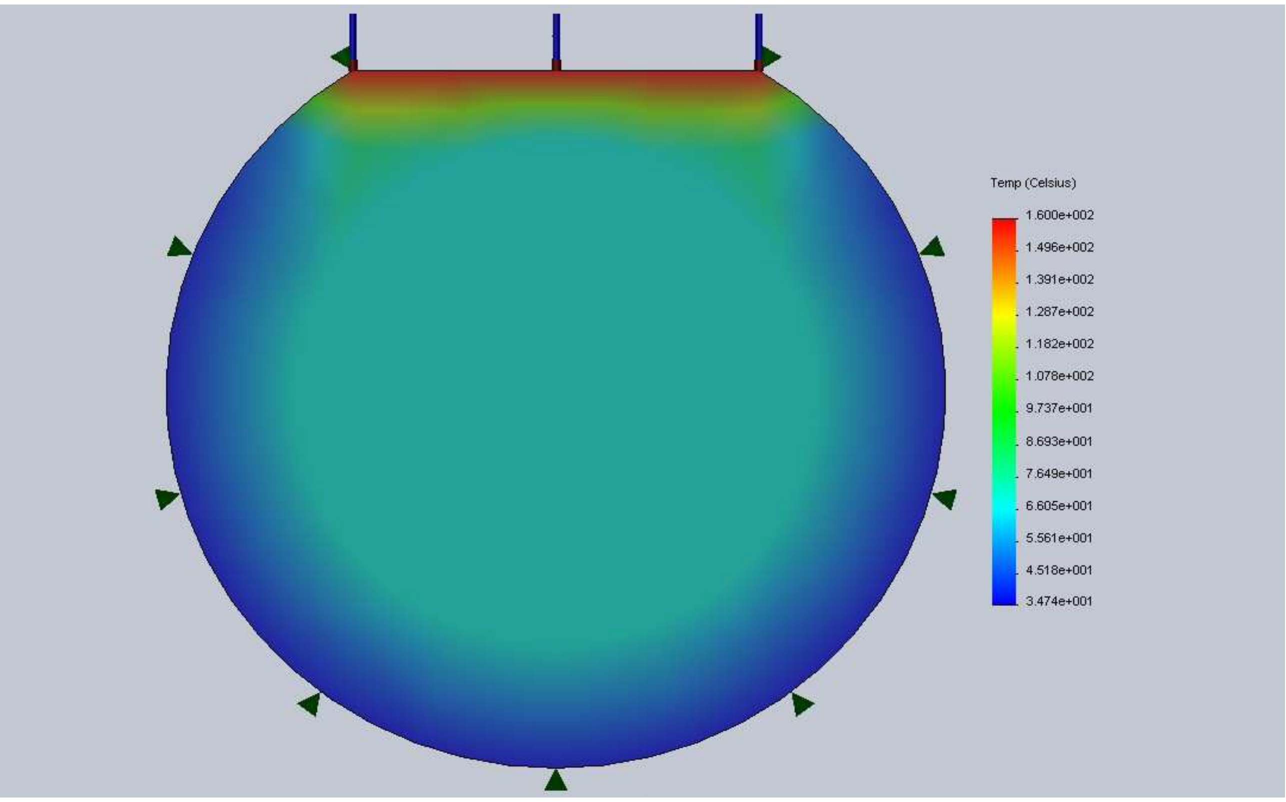

Fig 4. Temperature distribution in single-core cable (cross-section is shown) calculated with SolidWorks© Simulation software (material of conductor – copper, material of insulator – PVC, diameter of conductor – 4.6 mm, diameter of the cable – 6.8 mm)

5. Conclusions

1. Proposed two rolls insulator removal machine can be used by small cable production or waste recycling companies. One of the main advantages of machine is the possibility to keep the metal conductor of the cable undamaged and eliminate preparatory operations with the waste cables. The undamaged conductor can be recovered by plastic in further stages.
2. The recovered insulating material after the separation process is absolutely metal-free and can be reused without additional operations.
3. The optimal peripheral speed of the rolls (or linear cable speed) required to completely liberate polyvinylchloride insulating material from conductor of single-core cable depends on the diameter of the conductor. When diameter of copper conductor increases from 1.8 to 4.6 mm, optimal peripheral speed of the rolls must be reduced from 1.8 to 0.41 m/min (rotational speed of the rolls must be reduced from 6.5 to 1.5 rpm). When diameter of aluminum conductor increases from 1.8 to 4.6 mm, optimal peripheral speed of the rolls must be reduced from 1.64 to 0.29 m/min (rotational speed of the rolls must be reduced from 5.9 to 0.9 rpm).
4. The optimal peripheral speed of the rolls (or linear cable speed) required to completely liberate polyvinylchloride insulating material from conductor depends on the material of conductor of single-core cable. Insulating material can be removed from copper conductor cables at higher peripheral speed of the rolls as compared with aluminum conductor cables (1.1–1.4 times, depending on the diameter of conductor). This phenomenon can be explained by differences in thermal conductivities of the materials.

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