A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 59 2014 Issue 2
DOI: 10.2478/amm-2014-0111

M. SULIGA*

THE ANALYSIS OF THE MECHANICAL PROPERTIES OF HIGH CARBON STEEL WIRES AFTER MULTIPASS HIGH SPEED DRAWNING PROCESS IN CONVENTIONAL AND HYDRODYNAMIC DIES

ANALIZA WŁASNOŚCI MECHANICZNYCH DRUTÓW ZE STALI WYSOKOWĘGLOWEJ PO PROCESIE WIELOSTOPNIOWEGO CIĄGNIENIA Z DUŻYMI PRĘDKOŚCIAMI W CIĄGADŁACH KONWENCJONALNYCH I HYDRODYNAMICZNYCH

In this work the influence of the drawing speed on lubrication conditions and mechanical properties of high carbon steel wires drawn in conventional and hydrodynamic dies has been assessed. The drawing process of φ5.5 mm wires to the final wire of φ1.7 mm was conducted in 12 passes, in industrial conditions, by means of a modern Koch multi-die drawing machine. The drawing speeds in the last passes were: 5, 10, 15, 20 and 25 m/s. For final wires φ1.7 mm the investigation of mechanical properties has been carried out, in which yield strength, tensile strength, uniform and total elongation and also number of twists were determined. It has been shown that the increase of drawing speed from 5 m/s up to 25 m/s caused the increase by 6% strength properties and decrease of plasticity properties by 10%. Higher values of tensile strength and yield strength of the wires drawn conventionally with high speeds are associated with worse conditions, while in case of wires drawn hydrodynamically the main factor which caused the increase of strength properties was high lubricant pressure in hydrodynamic die, which caused the increase of total draft.

Keywords: drawing speed, lubricant conditions, conventional and hydrodynamic dies, mechanical properties

W pracy określono wpływ dużej prędkości ciągnienia na warunki smarowania i własności mechaniczne drutów ze stali wysokowęglowej ciągnionych w ciągadłach konwencjonalnych i hydrodynamicznych. Proces ciągnienia drutów o średnicy 5,5 mm na średnicę końcową 1,70 mm zrealizowano w 12 ciągach, w warunkach przemysłowych, na nowoczesnej ciągarce wielostopniowej Kocha. Prędkości ciągnienia na ostatnim ciągu wynosiły odpowiednio: 5, 10, 15, 20 i 25 m/s. Dla drutów φ1,70 mm przeprowadzono badania własności mechanicznych, w których określono umowną granicę plastyczności, wytrzymałość na rozciąganie, wydłużenie równomierne i całkowite oraz liczbę skręceń. Przeprowadzone badania wykazały, że wzrost prędkości ciągnienia z 5 do 25 m/s nie zależnie od metody ciągnienia, spowodował zwiększenie o około 6% własności wytrzymałościowych drutu, przy jednoczesnym około 10% spadku własności plastycznych. Wyższe wartości wytrzymałości na rozciąganie i granicy plastyczności w drutach ciągnionych konwencjonalnie z dużymi prędkościami, należy wiązać z gorszymi dla tego wariantu warunkami smarowania, natomiast w przypadku ciągnienia hydrodynamicznego głównym czynnikiem wzrostu własności wytrzymałościowych, był większy gniot całkowity spowodowany oddziaływaniem wysokiego ciśnienia smaru w ciągadle hydrodynamicznym.

1. Introduction

Whereas technical progress necessitates the producers of wire and wire products continuous improvement of manufacturing them. Another factor stimulating the development of drawing industry are economic considerations. In order to increase competitiveness in the global market modern factory wire are forced to seek new solutions in order to increase their productivity and reduce production costs while maintaining high quality of products drawn [1-2].

Nowadays the main direction of development and modernisation of wire drawing mills is the implementation of the technology of high speed drawing process of high carbon steel wires that have been used in manufacturing of ropes, springs and steel cord. The main obstacle in the implementation of this technology is intense heating of the surface layer of the wire that leads to the deterioration of lubrication, premature wear of dies and a decline in property wires below the applicable industry standards [1].

From the literature and the author's own research shows that poor lubrication conditions at high speed drawing in traditional technology drawing are associated with borax lubricant carrier that do not offer downloads and maintenance by drawing a sufficiently large amount of lubricant on the surface of drawn wires [3].

One of the known ways to improve the properties of high carbon wire drawing dies is the use of hydrodynamic creating conditions for complete separation of the friction surfaces and wire drawing dies, which in turn reduces the friction [4-5]. The use of this type of dies should have a positive impact

* CZESTOCHOWA UNIVERSITY OF TECHNOLOGY, FACULTY OF PRODUCTION ENGINEERING AND MATERIALS TECHNOLOGY, INSTITUTE OF METAL FORMING AND SAFETY ENGINEERING, 42-200 CZĘSTOCHOWA, 19 ARMII KRAJOWEJ STR., POLAND

on the lubrication conditions and properties of drawn wires at speeds above 15 m/s. In the last 40 years a lot of work was carried out, which showed that the process of high carbon wire drawing dies in hydrodynamic properties enables significant improvement of wires, but for the most part, these studies are single-stage drawing on drawing machines with relatively low speeds not exceeding 2 m/s [6-7]. However, very few reports describing the multipass drawing process in hydrodynamic dies at speeds in excess of 7 m/s [8-9].

Therefore, the aim of this study is to determine the effect of high drawing speed in conventional and hydrodynamic dies on lubrication conditions and mechanical properties of high carbon steel wires.

2. Material and applied drawing technologies

The investigation of high speed multipass drawing process in conventional and hydrodynamic dies performed for high carbon steel wire grade C78D (0.79% C). Before drawing, the wire rod was patented, itched and phosphated. The drawing process of φ5.5 mm wires in the final wire of φ1.7 mm was conducted in 12 passes, in industrial conditions, by means of a modern multi-die drawing machine Koch KGT 25/12, using conventional and hydrodynamic dies (Fig. 1) with an angle of drawing $2\alpha = 12°$. The drawing speeds in the last pass, depending on the variant of the drawing, was respectively: 5, 10, 15, 20, 25. Individual drafts, G_p, total draft, G_c, and drawing speeds, v are summarized in Table 1.

TABLE 1

Distribution of individual drafts G_p, total draft G_c and drawing speeds v in particular drafts for wires drawn in conventional (K variant) and hydrodynamic dies (variant H)

Draft	φ, mm	G_p, %	G_c, %	v, m/s				
				A	B	C	D	E
0	5.50	–	–	–	–	–	–	–
1	5.00	17.4	17.4	0.58	1.16	1.73	2.31	2.89
2	4.48	19.7	33.7	0.72	1.44	2.16	2.88	3.60
3	4.00	20.3	47.1	0.90	1.81	2.71	3.61	4.52
4	3.60	19.0	57.2	1.12	2.23	3.35	4.46	5.58
5	3.24	19.0	65.3	1.38	2.75	4.13	5.51	6.88
6	2.92	18.8	71.8	1.70	3.39	5.08	6.78	8.47
7	2.64	18.3	77.0	2.07	4.15	6.22	8.29	10.37
8	2.40	17.4	81.0	2.51	5.02	7.53	10.04	12.54
9	2.19	16.7	84.2	3.01	6.03	9.04	12.05	15.06
10	2.01	15.8	86.6	3.58	7.15	10.73	14.31	17.88
11	1.85	15.3	88.7	4.22	8.44	12.67	16.89	21.11
12	1.70	15.6	90.5	5	10	15	20	25

As a lubricant in the high speed multipass drawing process the next-generation multicomponent LUBRIFIL VA7798 drawing powder, which is a mixture of sodium soaps and inorganic additives. Additionally, in order to improve the lubrication of the first draft installed the rotating die (die speed was 15 rev/min).

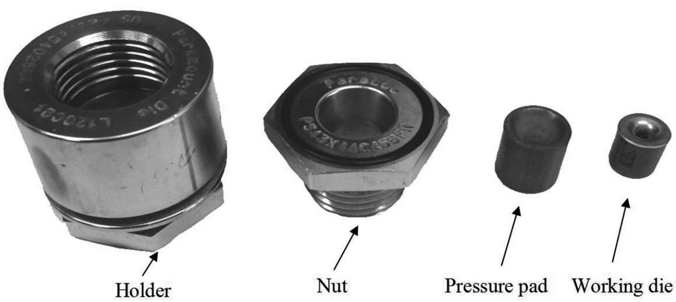

Fig. 1. Paramount hydrodynamic die TR4 type, casing B type

3. Results and discussion

In order to establish the effect of drawing speed and drawing methods on lubrication conditions the amount of lubricant on the surface of final φ1.7 mm wires was estimated. The results are presented in Fig 2.

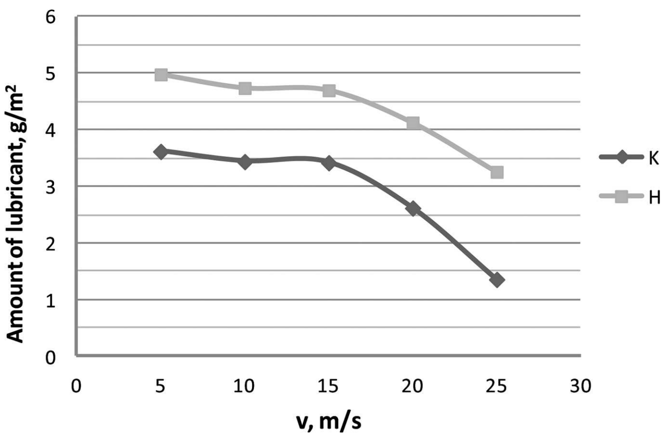

Fig. 2. The influence of drawing speed on the amount of lubricant on the surface of final φ1.7 mm wires drawn in conventional (K) and hydrodynamic (H) dies

The results presented in Fig. 2 demonstrate the negative impact of high speed drawing on lubrication conditions. While differences in the amount of lubricant on the wires drawn with speed 5÷15 m/s are small, whereas for wires drawn at a speed of 20 m/s the differences are significant. Further increasing the drawing speed results in a rapid deterioration of lubrication, especially for conventional drawing, in which at v=25 m/s were almost threefold decrease in the amount of lubricant on the wires (down from 3.62 to 1.32 g/m^2). However, the use of hydrodynamic dies reduces significantly negative impact on the high speed drawing lubrication conditions, confirming the still relatively large amount of lubricant on the surface of the wires, at v=25 m/s, it was about 3.26 g/m^2. The difference in the amount of lubricant on the surface of drawn wires in conventional and hydrodynamic dies in the last over at v=25 m/s is equal to about 140%.

In high speed wire drawing process the lubrication conditions in essential way influences on drawing parameters and properties of wires, including mechanical properties. Mechanical investigation was carried on a Zwick Z100 testing machine and on ZKZE 01/1 torsion machine, according to PN-EN

10218-1:2012 standard. For final wires φ1.7 mm, the following was determined: yield point, $R_{0.2}$; ultimate tensile strength, R_m; coefficient, $R_{0.2}/R_m$; uniform elongation, A_r; total elongation, A_c; number of twists N_t. The changing of $R_{0.2}$ and R_m in drawing speed function are presented in Fig. 3÷4.

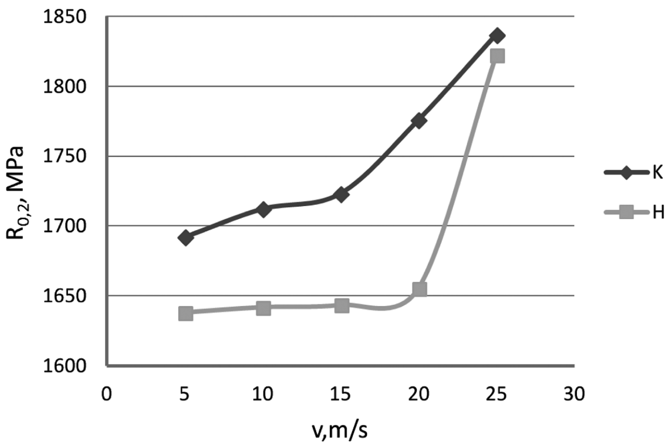

Fig. 3. The changing of yield point $R_{0,2}$ for φ1.7 mm final wires drawn in conventional (K) and hydrodynamic (H) dies in drawing speed function

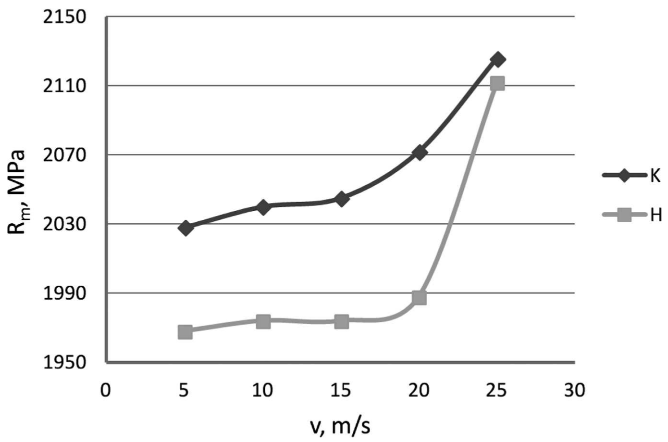

Fig. 4. The changing of ultimate tensile strength R_m for φ1.7 mm final wires drawn in conventional (K) and hydrodynamic (H) dies in drawing speed function

Based on the results shown in Figures 3 and 4 it can be concluded that the drawing speed substantially affect on strength properties of high carbon steel wires. Wires drawn in with speed 25 m/s, in relation to the wires of conventional dies towed at a speed of 5 m/s, characterized by, respectively, 8.6% higher yield strength, and 4, 8% increase in tensile strength. The higher strength properties of wires drawn in conventional dies at high speeds (v=25 m/s) should be associated with the greater strengthening of its sublayers, caused by deterioration of the lubrication. The increase in drawing speed also resulted in an increase in the strength properties of wires drawn in hydrodynamic dies. However, unlike the conventional drawing wires increase work hardening in the wires drawn in hydrodynamic dies at a speed of v=25 m/s (HE variant), is mainly due to their higher total draft. Too high value of pressure in hydrodynamic die in last draft, much larger than yield stress caused additional work hardening of wire, much higher that expected from the final diameter dk of die. Diameter wires with HE variant, in contrast to the other drawing variants varied in the range 1.60÷1.66 mm (average 1.63 mm). For wires drawn in hydrodynamic dies with speed 5÷20 m/s there were no dimensional deviation.Thus, for the same diameter of the final wire of 1.7 mm and a very good lubrication conditions increase drawing speed of 5 to 20 m/s did not affect significantly the mechanical properties of the wires.

The application of hydrodynamic dies in multipass drawing process with high speeds result the decrease of work hardening, as confirmed by lower $R_{0,2}$ and R_m values (Fig. 3 and 4). Lower values of $R_{0,2}$ and R_m in 1.63 mm wires drawn in hydrodynamic dies with speed 25 m/s, in comparison to the wires drawn in conventional dies with speed of 25 m/s, providing a much smaller for this variant redundant strain.

The increase of strength properties of wires drawn with high speeds caused the deteriorating of plasticity properties, what confirm $R_{0,2}/R_m$ coefficient. This coefficient makes possible to estimate the wire deformability (the lower the ratio, the more plastic material). On Fig. 5 the changing of $R_{0.2}/R_m$ coefficient in drawing speed function is presented.

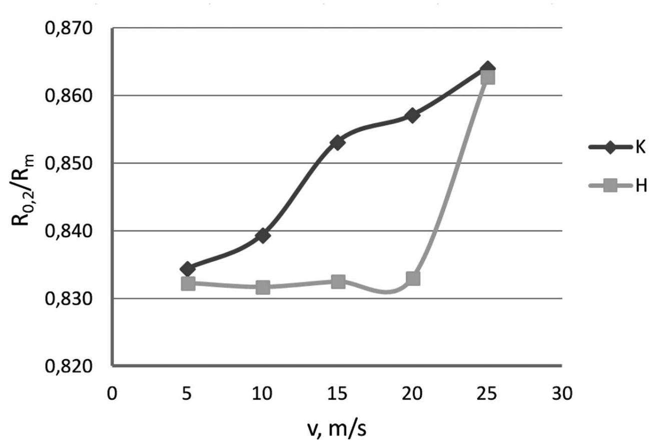

Fig. 5. The changing of coefficient, $R_{0.2}/R_m$ for φ1.7 mm final wires drawn in conventional (K) and hydrodynamic (H) dies in drawing speed function

The data presented in Fig. 5 shows that the use of hydrodynamic dies in multipass drawing process "slow" decline in the plasticity properties of wires drawn with high speed and "shifts" the rapid growth of work hardening towards higher strain.

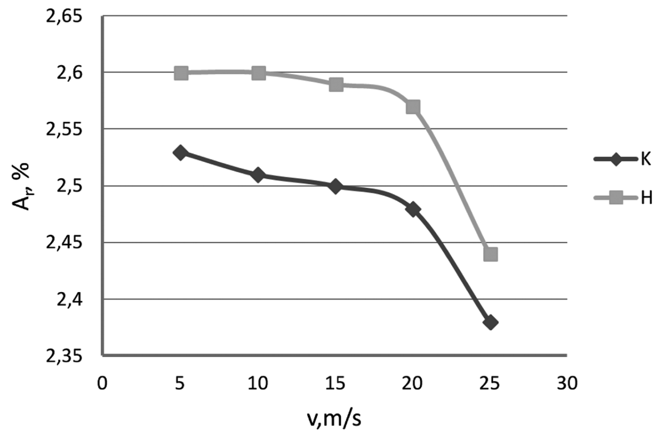

Fig. 6. The changing of uniform elongation A_r for φ1.7 mm final wires drawn in conventional (K) and hydrodynamic (H) dies in drawing speed function

On Fig. 6 and 7 the changing of uniform elongation A_r and total elongation A_c of wires in drawing speed function is shown.

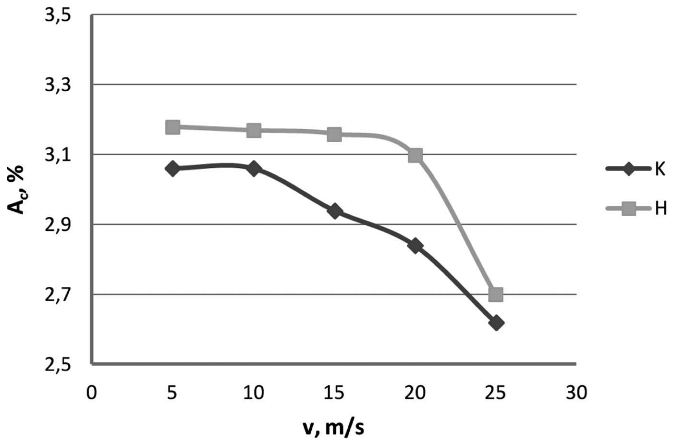

Fig. 7. The changing of total elongation A_c for φ1.7 mm final wires drawn in conventional (K) and hydrodynamic (H) dies in drawing speed function

The results presented in Fig 6 and 7 confirms the negative effect of high speed on the plasticity properties of wires. The increase in drawing speed of 5 to 25 m/s caused a decrease of plasticity properties of wires drawn conventionally and hydrodynamically, respectively, 14% and 7%. The analysis of the data contained in Fig. 6 and 7 also shows that drawing in hydrodynamic lubrication conditions significantly improve plastic properties of the wires, as evidenced by the higher values of A_r and A_c.

The basic parameters defining the properties of drawn wires and commonly used in industry is the number of twists N_t, which reflect the actual state of the material in a way. Number twists of drawn wires determine by both their strength and their plasticity. On Fig. 8 the influence of drawing speed and drawing method on number of twist of 1.7 mm final wires.

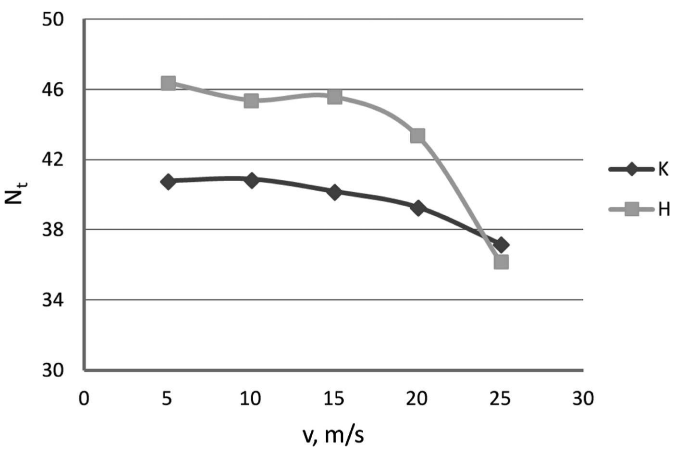

Fig. 8. The changing of number of twists N_t for φ1.7 mm final wires drawn in conventional (K) and hydrodynamic (H) dies in drawing speed function

Based on the results shown in Fig. 8 it can be concluded that the drawing speed substantially affect the resulting number of twists. Wires from variant K (conventional die) and H (hydrodynamic dies) drawn at a speed of 25 m/s, relative to the wires drawn at a speed of 5 m/s, characterized by respectively 3.1% and 8.8% lower number of twists. Decrease in the number of twists in the wires drawn in conventional dies at high speeds is caused by larger inhomogeneity of deformation. However, in the case of drawn wires in dies hydrodynamic dies rapid decline in the number of twists at a speed of 25 m/s to be associated with higher strength properties, worse plasticity properties and more inhomogeneous subsurface layer of wire resulting from a surface waviness of wire, due to the influence of high pressure lubricant in die during the drawing process.

4. Conclusion

From the experimental tests carried out, the following findings and conclusions are drawn:

1. Analysis of changes in properties of the wires showed that the drawing speed and method of drawing significantly affect the lubrication conditions and mechanical properties of high carbon steel wires.
2. In terms of the mechanical properties was found that the increase in drawing speed of 5 to 25 m/s resulted in an increase of approximately 6% of the strength properties of the wire, while approximately 10% decrease plastic properties.
3. Higher values of tensile strength and yield strength of the wires conventionally drawn at high speeds, providing a greater work hardening of the subsurface layers, which should be associated with worse lubrication conditions for this variants. In the case of wires drawn in hydrodynamic dies the main factor of increasing of strength properties was additional strain caused too high value of lubricant pressure in hydrodynamic die.
4. The negative effect of high drawing speed (above 20 m/s) also appeared to decrease the number of twists of wire, regardless of the method of drawing.
5. The application of hydrodynamic dies in high speed drawing process in essential way reduces the negative effect of high speeds on the lubrication conditions and significantly improves the mechanical properties of drawn wires.
6. The deployment of new drawing technology, resting upon the application of phosphate lubricant carrier, multicomponent drawing powder and hydrodynamic dies should enable to improve the quality of produced wires and contribute to increasing the efficiency of production in drawing plants.

REFERENCES

[1] M. S u l i g a, Analiza wielostopniowego ciągnienia drutów stalowych z dużymi prędkościami w ciągadłach konwencjonalnych i hydrodynamicznych, Seria Monografie nr 32, Wyd. Wydz. Inżynierii Procesowej, Materiałowej i Fizyki Stosowanej Politechniki Częstochowskiej, Częstochowa 2013.

[2] M. S u l i g a, The influence of the high speed multipass drawing process on the fatigue strength of high carbon steel wires, Archives of Metallurgy and Materials **57**, 4, 1171-1178 (2012).

[3] M. S u l i g a, Wpływ smarów i warstw podsmarowych w procesie ciągnienia wielostopniowego na warunki smarowania i własności mechaniczno-technologiczne drutów ze

stali wysokowęglowych, Metallurgist-Metallurgical News (Hutnik-Wiadomości Hutnicze) **5**, 339-342 (2013).
[4] J. Łuksza, A. Skołyszewski, F. Witek, W. Zachariasz, Druty ze stali i stopów specjalnych, Wydawnictwo Naukowo-Techniczne, Warszawa (2006).
[5] M. Suliga, The influence of the multipass drawing process in classical and hydrodynamic dies on residual stresses of high carbon steel wires. Archives of Metallurgy and Materials **56**, 4, 939-944 (2011).
[6] J.W. Pilarczyk, Analiza przyczyn zmian własności drutów ciągnionych konwencjonalnie i w ciągadłach ciśnieniowych, Seria Monografie nr 39, Politechnika Częstochowska, Częstochowa (1996).
[7] L. Sadok, Nowe aspekty ciągnienia rur w warunkach tarcia hydrodynamicznego, ZN AGH, Metalurgia i Odlewnictwo nr 73 (1976).
[8] M. Suliga, R. Kruzel, The mechanical properties of high carbon steel wires drawn in conventional and hydrodynamic dies, Metalurgija **52**, 1, 43-46 (2013).
[9] V. Bitkov, Research of wire drawing under conditions of hydrodynamic friction, Wire & Cable Technology International, March, 94-97 (2006).

Received: 20 January 2014.