An Investigation of the Effect of Cutting Parameters on Surface Quality and Tool Wear in Parawood Machining Process

Supasit Rodkwan[1,2,]* and Siripen Supadarattanawong[1]

Department of Mechanical Engineering[1],
Research and Development Institute of Industrial Production Technology (RDiPT)[2],
Faculty of Engineering, Kasetsart University,
50 Paholyothin Rd., Jatujak, Bangkok, Thailand, 10900
Tel: 0-2942-8555 ext. 1842, Fax: 0-2579-4576, E-mail address: fengssr@ku.ac.th*

บทคัดย่อ

งานวิจัยนี้เป็นแสดงถึงการตัดไม้ยางพาราด้วยเครื่องกัดซีเอ็นซีสำหรับงานไม้ (Computer Numerical Control, CNC, Wood Router) โดยได้ศึกษาถึงค่าของตัวแปรต่างๆ ที่มีอิทธิพลต่อการตัดไม้ยางพารา เช่น ความเร็วในการตัด อัตราการป้อน ความลึกในการตัด ที่มีผลต่อความเรียบของผิวชิ้นงาน และความสึกของมีดตัดทังสเตนคาร์ไบด์ (Tungsten Carbide, TC) ผลจากการวิจัยพบว่าสภาวะที่เหมาะสมในการตัดไม้ยางพาราเพื่อให้ได้ผิวของชิ้นงานที่มีคุณภาพดีที่สุดในขอบเขตที่ศึกษาคือที่ความเร็วรอบ 12,000 rpm อัตราการป้อน 180 ipm และที่ความลึกของการตัด 0.0625 นิ้ว โดยสภาวะที่ทำให้เกิดความสึกของมีดตัด TC น้อยที่สุดและเกิดขุยไม้น้อยที่สุดคือ ที่ความเร็วรอบ 12,000 rpm อัตราการป้อน 360 ipm และที่ความลึกของการตัด 0.125 นิ้ว ผลการวิจัยนี้จะสามารถช่วยให้เข้าใจถึงสภาวะที่เหมาะสมในกระบวนการตัดไม้ยางพาราเพื่อให้ได้คุณภาพของผิวชิ้นงานดีที่สุดโดยสามารถลดอัตราการสึกหรอของมีดตัด ลดการสูญเสียของวัสดุ พร้อมทั้งลดเวลาในกระบวนการตัดซึ่งตัวแปรที่เหมาะสมสามารถช่วยเพิ่มผลผลิตในอุตสาหกรรมการผลิตเฟอร์นิเจอร์ไม้ยางพาราในส่วนของการพัฒนาส่วนการผลิต

คำสำคัญ : ยางพารา, คุณภาพของผิวชิ้นงาน, ความสึกของมีดตัด CNC, มีดตัดทังสเตนคาร์ไบด์

Abstract:

In this research, series of machining processes of parawood were carried out on a Computer Numerical Control (CNC) wood router to investigate the effect of various machining parameters such as spindle speed, feed speed, depth of cut on the quality of parawood machined surface and the wear of the Tungsten Carbide (TC) cutting tool insert. It was discovered that the optimal cutting conditions for the range of machining parameters studied in this research considering the surface quality include a spindle speed of 12,000 revolutions per minute, a feed speed of 180 inch per minute and a depth of cut 0.0625 inch. In addition, the conditions with the least cutting tool wear and the least splinter were found at a spindle speed of 12,000 revolutions per minutes, a feed speed of 360 inch per minute and a depth of cut 0.125 inch. The results provide more understanding on parawood machining process in order to identify the optimal cutting condition where high quality machined surfaces with less surface roughness, less tooling cost, less waste materials, and lower production time are obtained. The selection of optimal machining parameters can be greatly benefited to the parawood furniture manufacturing industry in term of a productivity improvement.

Keyword: Parawood, Surface quality, Tool wear, CNC, TC.

1. Introduction

In the past few years, wood machining has often been treated as the last factor on improving productivity as an integrated part in furniture manufacturing; nevertheless, with growing concern on the future supply of wood resources, it becomes significant for researchers to gain a better understanding of wood machining process nowadays. Currently, parawood becomes more popular as an important raw material in Thailand furniture manufacturing industry due to unique properties of parawood such as excellent white wood texture and color like high quality hardwoods. In addition, parawood can be generally obtained from rubber plants which are mostly found in Eastern and Southern Thailand. Consequently, in order to improve the productivity of using parawood in furniture manufacturing industry, more understanding of parawood machining process and its optimal cutting condition are needed to acquire high quality wood products and to reduce production time with less tooling cost and less waste materials.

Wood machining is normally performed under very high cutting speed and the extremely sharp cutting edges are needed. It is a predominantly abrasive process and therefore the erosion of the cutting tool material is the main wear mechanism. Low wedge angles are necessary for machining massive wood and generally give a better surface quality; however, the lower angle the higher the wear (Endler, et. al., 1999). The amount of wear generally decreases with an increase in hardness, a decrease in grain size and a decrease in binder content of the cutting tool material. Several wear mechanisms may contribute to the overall wear of the cutting tool. Among these wear mechanisms are gross fracture or chipping, abrasion, erosion, microfracture, chemical and electrochemical corrosion and oxidation. Corrosion can be easily removed from the cutting edge by abrasion depending on the cutting condition e.g., moisture content, composition, etc. (Sheikh-Ahmad and Bailey, 1999). Some wear could occur through tool edge chipping when wood products which have low moisture content (dry) are machined. Tool life and tool performance in a given operation improve considerably when the cemented tungsten carbides are used in place of either high carbon steel or high speed steels (Bailey, et. al, 1983).

In general, most research has focused on primary wood production processes needed to produce materials with specific characteristics. There are many different methods to cut materials; routing process is often used to compare different material's wear on the cutting tool. There are distinct characteristics in tool wear and surface roughness among different wood fiber plastic products. Differences also exist when these materials are compared to solid wood. A better understanding of the necessary process parameters to cut these materials will lead to the improved results with respect to tool wear and surface roughness (Buehlmann, et. al, 2001). Researchers have attempted to gain more understanding in wood machining process. The relationship between the cutting process parameters such as feed rate, cutting speed and wood machining productivity was developed (Diei and Dornfeld, 1987). The effects of tool wear, cutting direction, spindle speed on edge chipping of melamine coated particle board using a CNC wood router was studied. The relationship of work piece quality, tool wear and machining conditions was also verified with the empirical monitoring indices. (Rodkwan, 2000).

The investigation of mechanics of machining for other materials, besides metals and wood, such as elastomers were also performed (Rodkwan and Strenkowski, 2003), (Strenkowski, et. al., 2003), (Strenkowski, et. al, 2002). In their research, the effects of various machining parameters on chip morphology, surface roughness and the associated machining force were examined using the orthogonal cutting test of elastomers. The feed speed and rake angle were found to have significant effect on the type of chips generated during orthogonal cutting (Rodkwan, 2002).

Currently, parawood makes up seventy percents of raw materials used in Thai wooden furniture industry (AsiaPulse News, 2003). Nevertheless, a little research has been performed in understanding various furniture manufacturing processes such as machining, sanding using parawood. The use of Computer Numerical Control (CNC) wood router to machine parawood Laminated Veneer Lumber (LVL) and solid parawood using cemented tungsten carbide tool was carried out (Ratnasingam and Perkins, 1998). In this work, it was found that the tool wear rate and power consumption are increased as cutting continues. Parawood LVL was also discovered to be four times as abrasive as solid parawood. The fundamental understanding of parawood sanding process was revealed (Ratnasingam, et. al., 2002). It was found that sanding of parawood using silicon carbide abrasive belts was performed better than using aluminum oxide abrasive belt. The optimal cutting conditions of parawood machining using a Polycrystal Diamond (PCD) cutting tool ware investigated (Prommul, et. al., 2002). In this work, spindle speed, feed rate and cutting direction are the major controlled parameters to study their effects on surface roughness and wood splinter. It was discovered that the condition which has the best surface finish and no wood splinter was occurred at the spindle speed of 15,000 rpm and feed rate of 8 m/min. The best surface quality of parawood were found when the spindle speed of 16,000 rpm and feed speed rate of 12 m/min were used with Tungsten Carbide (WC - TC) cutting tool (Arlai, et. al., 2003).

2. Experiment Setup

2.1 Materials and Tools

Solid parawood supplied by Hand&Heart Company in Thailand was selected as the workpiece material. In addition, maple wood was supplied by Wood Machining & Tooling Research Program (WMTRP) at North Carolina State University for comparison purpose. The workpiece geometry is 39.4 in. in length, 4 in. in width and 1 in. in board thickness. The mean specific gravity of parawood is 0.557 and the moisture content is 12 ± 2%. Tungsten carbide grade H3F with 3% cobalt binder insert type was used throughout the experiment as the cutting blade since it is one of blade types widely used in wood machining industry. The geometry of insert is 1.181 in. in length, 0.472 in. in width and 0.059 in. in blade thickness. A Thermwood model 40 Turret CNC wood router was used in the research. It has a capacity up to nine horsepower, maximum spindle speed of 20,000 revolution per minute (rpm) and the machining travel is 60 x 60 x 6 in. Workpiece was mounted rigidly on a CNC machine table though specifically-designed vacuum system.

2.2 Measurements and analyses

In this work, Material Removal Rate (MRR), surface quality of machined parawood and the cutting tool wear were monitored. The surface roughness was measured off-line using a stylus-type profilometer, by Mitutoyo. In addition, tool wear for both unused and worn inserts was also measured off-line using Keyence optical microscope model VH-6100 with lighting and digital picture capturing. A total of three repetitions of tests were performed. The average of these three repetitions was then presented.

2.3 Procedures

The procedure for the tool wear and surface quality investigation is described as follows: (1) identify the workpiece and measure the nose width of all inserts, (2) clamp the wood sample for the test on the CNC wood router table and set up spindle speed, feed rate and depth of cut following the experiment design shown in Table 1., then place the blade into the blade-holder for the first cut and next run for one pass to clean up the edge of workpiece, then stop the router, (3) replace the blade and place test's insert into the blade-holder, (4) run the test for 1000 linear feet and measure the nose width of each insert and take the pictures using microscope. Next, calculate arithmetic for the nose width, (5) repeat step (2) to step (4) again for the insert in 1000 increments linear feet, stopping at 2000, 3000 linear feet to measure surfaces roughness and calculate the arithmetic average surface roughness of workpiece and take pictures and calculate the arithmetic average of chip size after 3000 linear feet of machining, (6) after three replications, calculate the average of the arithmetic average of surface roughness and nose width of workpiece and test blades. In addition, maple woods were also used in specific cutting series in similar cutting conditions of parawood to compare the tool wear and the quality of workpiece when the both types of materials are machined.

Table1. The cutting conditions used in this research.

Spindle Speed (rpm)	Feed Rate (ipm)	Deep of cut (inch)	Cutting Distance (feet)			Result
12,000	180	0.0625	1000	2000	3000	nose width
			1000	2000	3000	roughness
		0.125	1000	2000	3000	nose width
			1000	2000	3000	roughness
12,000	360	0.0625	1000	2000	3000	nose width
			1000	2000	3000	roughness
		0.125	1000	2000	3000	nose width
			1000	2000	3000	roughness
18,000	360	0.0625	1000	2000	3000	nose width
			1000	2000	3000	roughness
12,000	360	0.0625	1000	2000	3000	nose width
			1000	2000	3000	roughness

3. Results

For convenience, the codes were set to facilitate the analysis of results. The code settings are shown in Table 2.

Table 2. The code settings for experimental variables.

Spindle Speed (rpm)	code	Feed Rate (ipm),(a)	code	Deoth of Cut (inch),(b)	code
12,000	1	180	+	0.0625	+
18,000	2	360	-	0.125	-

The results obtained are shown in Table 3. Parawood and maple wood were denoted as PW and MP, respectively, for ease of the representation.

Table 3. Results from the machining tests.

PW	Variables			Nose Width (µinch)				Roughness (µinch)	Machining Time (hr:min:sec)
				Cutting Distance					
	rpm	a	b	0	1000	2000	3000		
1	1	+	+	133.858	310.629	343.385	379.094	121.593	4:47:24
2	1	+	-	138.622	333.700	357.716	374.448	166.593	4:55:43
3	1	-	+	150.866	371.850	402.125	429.054	175.773	3:11:32
4	1	-	-	138.386	299.724	332.283	352.086	142.296	3:34:05
7	2	-	+	148.346	304.606	341.692	366.298	128.741	3:23:11
MP	1	-	+	138.110	293.700	330.856	350.984	166.037	3:36:58

The nose widths of insert for each cutting condition are shown in Figure 1. – 5. for parawood and Figure 6. for maple wood. The averages of tool wear in Figure 1. to 6. was found to be 121.593, 166.593, 175.778, 142.296, 128.741, 166.037 µinch respectively.

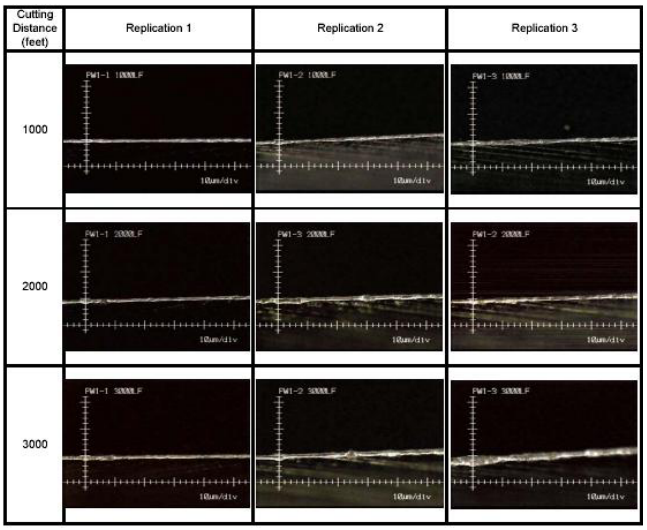

Figure 1. Nose width of an H3N insert at 12000 rpm, 180 ipm, depth of cut 0.0625 inch and width of cut 0.375 inch.

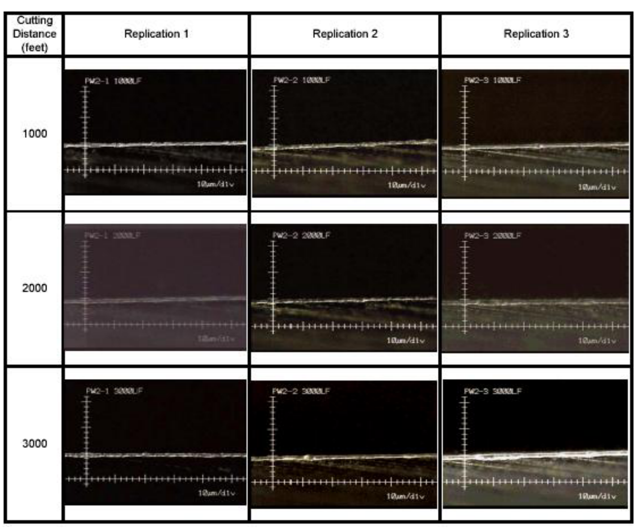

Figure 2. Nose width of an H3N insert at 12000 rpm, 180 ipm, depth of cut 0.125 inch and width of cut 0.375 inch.

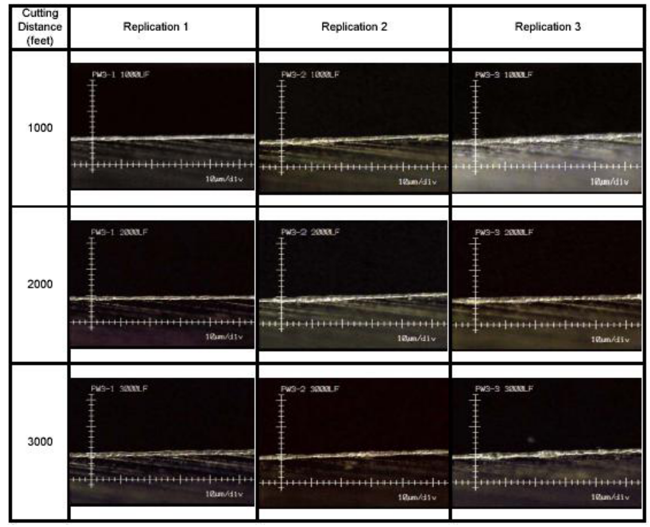

Figure 3. Nose width of an H3N insert at 12000 rpm, 360 ipm, depth of cut 0.0625 inch and width of cut 0.375 inch.

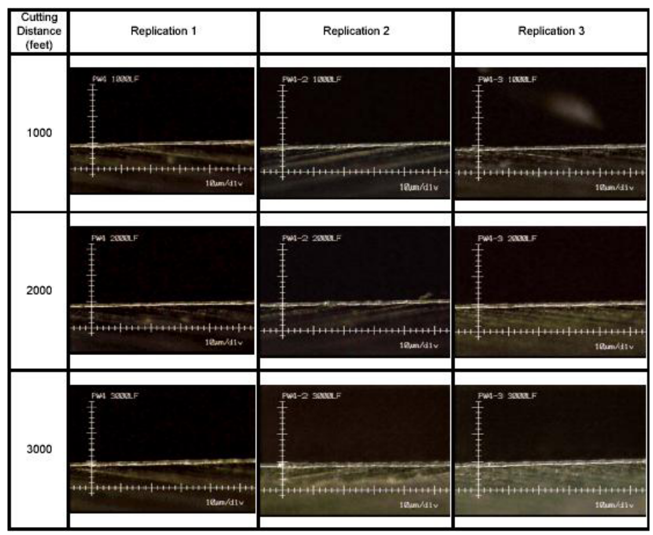

Figure 4. Nose width of an H3N insert at 12000 rpm, 360 ipm, depth of cut 0.125 inch and width of cut 0.375 inch.

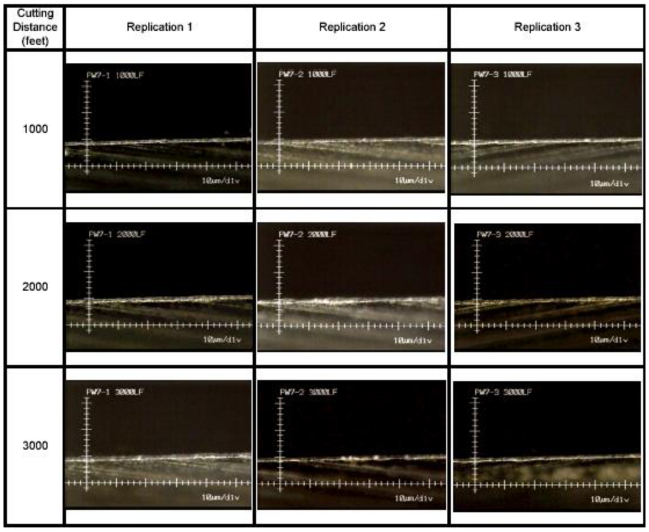

Figure 5. Nose width of an H3N insert at 18000 rpm, 360 ipm, depth of cut 0.0625 inch and width of cut 0.375 inch.

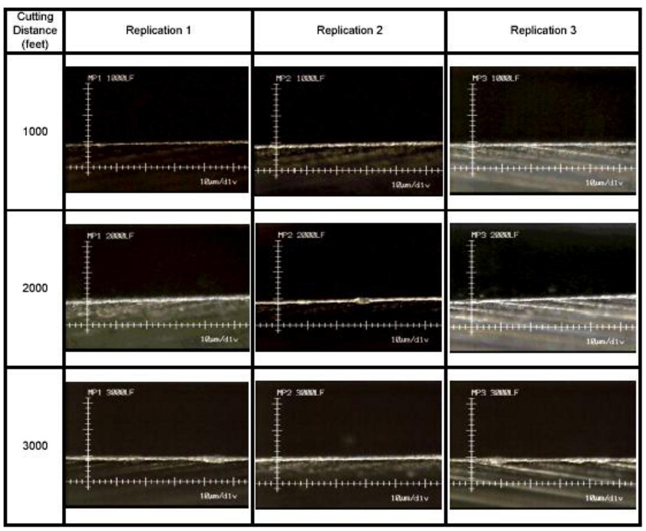

Figure 6. Nose width of an H3N insert at 12000 rpm, 360 ipm, depth of cut 0.0625 inch and width of cut 0.375 inch.

4. Conclusions

The investigation on the machined surface quality and tool wear when cutting parawood material revealed that the best surface quality were found at a spindle speed of 12,000 revolutions per minute, a feed speed of 180 inch per minute and a depth of cut of 0.0625 inch. In addition, the conditions with the least cutting tool wear and the least splinter were discovered at a spindle speed of 12,000 revolutions per minutes, a feed speed of 360 inch per minute and a depth of cut 0.125 inch. The results provide more understanding on parawood machining process in order to identify the optimal cutting condition where high quality machined surfaces with less surface roughness, less tooling cost, less waste materials, and lower production time are obtained. The selection of optimal machining parameters can be greatly benefited to the parawood furniture manufacturing industry in term of a productivity improvement.

5. Acknowledgements

I am very grateful to Dr. Supasit Rodkwan, the chairman of my MS Degree advisory committee, for his invaluable support, guidance and endless encouragement. I also would like to thank Mr. Richard L. Lemaster, Daniel E. Saloni, Timothy J. Horn who support and guidance on my research during a six-month period at Wood Machining & Tooling Research Program (WMTRP), College of Natural Science, North Carolina State University. Finally, I am greaty appreciate the Hand & Heart Company in Thailand for providing parawood materials.

6. References

Arlai, T., P. Kaewtatip and K. Prommul. 2003. Influences of Various Working Parameter in Routing Process of Rubber Wood Using Tungsten-Carbide Routers. **ME-NETT#17 National Conference**, Prajinburi.

AsiaPulse News. 2003. Diary-Thailand Fair to Promote Parawood Furniture.

Internet resource: http://www.asiapulse.com/

Bailey, J. A., A. M. Bayoumi and, J. S. Stewart. 1983. Wear of some Cemented Tungsten Carbide tools In Machining Oak. **Wear**. 85: 69-79.

Buehlmann, U., D.E. Saloni and R.L. Lemaster. 2001. **Abrasive Machining of Wood Plastic Composites**. Research Project Technical Summary Wood Machining and Tooling Research Program. North Carolina State University, Raleigh, North Carolina, USA.

Diei, E.N., and D.A Dornfeld. 1987. Acoustic Emission Sensing of Tool Wear in Face Milling. **Journal of Engineering for Industry**. 109 (3): 234-240.

Endler, I., K. Bartsch, A. Leonhardt, H. J. Scheibe, H. Ziegele, I. Fuchs and Ch. Raatz. 1999. Preparation and Wear Behavior of Woodworking Tools Coats with Superhard Layers. **Diamond and Related Materials**. 8: 834-839.

Prommul, K., P. Kaewtatip and T. Arlai. 2002. Study on Optimum Wood Cutting Conditions Using PCD. **ME-NETT#16 National Conference**, Phuket.

Ratnasingam, J., H. F. Reid and M.C. Perkins. 2002. The Abrasive Sanding of Rubberwood (hevea Brasiliensis) an Industrial Perspective. **Holz als Roh-und Werkstoff.** 60 (1): 191-196.

Ratnasingam, J., and M.C. Perkins. 1998. An Investigation into The Tool Wearing Characteristics of Rubberwood (Hevea Brasiliensis) Laminated Veneer Lumber. **Holz als Roh-und Werkstoff**. 56 (1): 31-35.

Rodkwan, S. and J. S. Strenkowski. 2003. A Numerical and Experimental Investigation of the Machinability of Elastomers. **ME-NETT#17 National Conference**, Prajinburi.

Rodkwan, S. 2002. **A Numerical and Experimental Investigation of the Machinability of Elastomers.** Ph.D. Dissertation. Department of Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, North Carolina, USA.

Rodkwan, S. 2000. **In-Process Monitoring and Control on Routing of Melamine-Coated Medium Density Particleboard on a CNC Wood Router**. Research Project Technical Summary Wood Machining and Tooling Research Program. North Carolina State University, Raleigh, North Carolina, USA.

Sheikh-Ahmad, J. Y. and J.A. Bailey 1999. The Wear Characteristics of Some Cemented Tungsten Carbides in Machining Particleboard. **Wear**. 225-229: 256-266.

Strenkowski, J. S., A. J. Shih, S. Rodkwan, and M. A. Lewis. 2003. **Machining of Elastomers – Experimental and Numerical Investigation**. 2003 NSF Design. Service and Manufacturing Grantees and Research Conference. Birmingham, Alabama. Jan 6-9.

Strenkowski, J. S., A. J. Shih, M. A. Lewis, S. Rodkwan, and D. R. Poirier. 2002. **Machining of Elastomers.** 2002 NSF Design. Service and Manufacturing Grantees and Research Conference, San Juan, Puerto Rico. Jan. 4-7.