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A STUDY OF ROADWHEEL FAILURES MAGNITUDE - NATURE - CAUSES AND TESTING OF A CONCEPT TO PREVENT THEM

John W. Cameron

Army Tank-Automotive Command
Warren, Michigan

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FINAL REPORT

JULY 1975

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TACOM

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MOBILITY SYSTEMS LABORATORY

U.S. ARMY TANK AUTOMOTIVE COMMAND Warren, Michigan

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This is a study of roadwheel failures - magnitude - nature - causes, and of a concept to overcome these failures so that the life and reliability may be improved and thus, the availability of tracked vehicles may be improved to reduce fleet costs.

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FINAL TECHNICAL REPORT

on

A STUDY OF ROADWHEEL FAILURES
MAGNITUDE - NATURE - CAUSES
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for

U.S. ARMY TANK-AUTOMOTIVE COMMAND
ARMOR AND COMPONENTS DIVISION

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SUMMARY

The objective was to increase the reliability and life of roadwheels and thus the availabilit of tracked vehicles.

First a study was made to determine the magnitude of the problem and to determine the nature of and cause of the failures.

Then a concept was developed to overcome the bonding and chunking failures found to be most prevalent. This concept placed a steel rim or shroud over the rubber tire with the rubber compressed between the shroud and the wheel. The shroud was made with a flange to serve as a wear surface for the track center guides.

Twenty-four wheels were procured and tested to determine durability, change in ride quality, and change in noise level. The concept is considered to have promise but also disadvantages. Therefore, it is suggested that other concepts under consideration be given a first evaluation before selecting the best course for intensive effort.

CONCLUSIONS

Considering that there was no background of experience on which to base the design of the steel shroud and further considering that it was fabricated with a welded joint contrary to directions, the durability tests are considered successful in that it would very likely be possible to refine this design to improve on the reliability and life of standard roadwheels. However, there are also drawbacks to the design. Noise level tests indicated no change inside the vehicle but an increase outside the vehicle. The test driver felt the noise level was definitely higher. Since the vehicle, even with the standard rubber tired wheels, is at or slightly above the acceptable noise level careful consideration is essential. It is believed that the track design could be changed to help this situation for the steel shrouded wheel. It should also be pointed out that a change from a rubber tired idler to a solid steel idler in the past, to avoid problems with the rubber tire, has also contributed to the noise level. The ride quality becomes significantly more harsh with the steel shroud, especially at slower speeds and on the more gradual bumps as encountered on a dirt road. In addition, when a steel shroud does fail it is disgorged from the vehicle and could cause damage to the suspension or track or injury to nearby personnel in the process. These wheels at 45 pounds are approximately ten pounds heavier than standard wheels.

RECOMMENDATIONS

Before any further development of the steel shrouded wheel is undertaken it is recommended that alternate concepts should be considered such as a proposal to mold a combination tire of rubber surrounded by ultra high density polyethylene. The polyethylene shrinks more than the rubber and thus compresses the rubber. The standard steel wear plate would probably have to be retained.

Another concept which should be considered is one under investitation, in which urethane tires are used in place of rubber and with different bonding arrangements, such as welding expanded metal to the wheel rim. Both of these concepts could overcome the bonding and chunking problems. Neither of these concepts would cause as much deterioration in ride quality or increase in noise level.

It is also recommended that studies be undertaken to determine the effect of shear stresses in the rubber on the bond life as has been proposed. Also a study of the mechanisms of tire failure could show a relationship between tensile strength and bond failures which may be contrary to what is expected.

It is also recommended that the vehicle designers pay attention to the apparently great variation in the life of wheels at different positions on the vehicle with a view toward equalizing the life.

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INTRODUCTION

Scope of Work - The objective is to improve the reliability of roadwheels on tracked vehicles; to improve the availability of the tracked vehicles through reduction of downtime; and to reduce the overall cost attributable to roadwheels.

Magnitude of Problem - To determine the magnitude and significance of the problem existing data was sought. A report prepared by the TACOM Maintenance Directorate, Initial Materiel Support Division, entitled "Control Program M48A3 Tanks and M113/M113A1 APC's" was studied. This report is based on data collected by a trained group of Sergeants attached to specific field units in three areas of Vietnam over a period of three months. This data has been augmented by other data such as from TAERS and has been analyzed by four commercial companies whose individual reports are included. The particular reason for the study reported is the assessment of a 5,000 mile overhaul policy. Pertinent data is extracted and noted below.

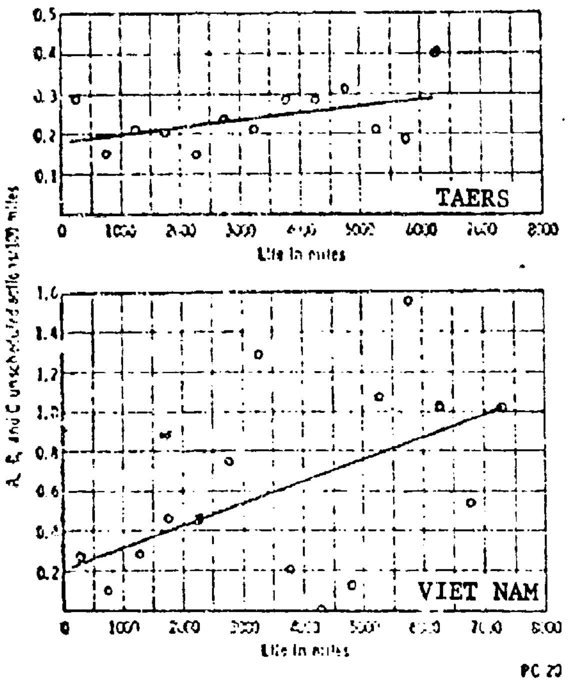
VIETNAM DATA (TACOM REPORT)

	M48A3	M113	M113A1
Total Vehicles	103	93	110
Total Manhours	2632.9	884.7	655.0
Total Actions	706	457	375
Total Parts Cost	$808,571	$85,158	$102,506
Total Miles	77,617	102,053	56,568
Average Days Covered	85	69	74
Average Miles Per Vehicle	982	1173	797
Average Miles Per Month	380	501	378
Average Cost Per Mile (Parts)	$10.41	$.83	$1.81
Average Cost Per Mile (Labor)	$ .20	$.05	$ .07

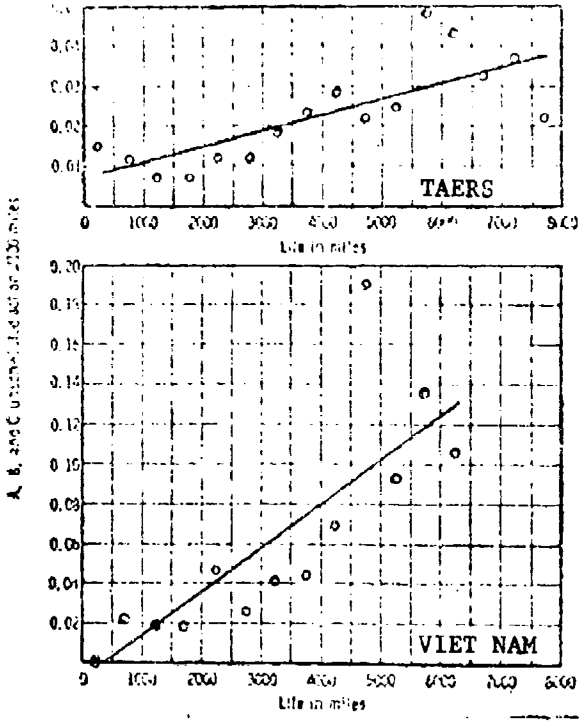
FROM THE ALLISON DIV OF GMC REPORT

Vehicle	Source	COMPONENT	ACTIONS #	ACTIONS % OF TOTAL	MTBF MILES	AVERAGE MANHOURS
M48A3 TANK	TAERS	Road and Idler Wheels	189	23.2*	1800	4.8
		Road, Idler and Suspension Hubs	62	7.6	5400	9.0
		Road and Idler Arms	62	7.6	5400	13.0
	VIETNAM	Road and Idler Wheels	71	19.1*	800	6.8
		Road, Idler and Suspension Hubs	23	6.2	2600	5.6
		Road and Idler Arms	22	5.9	2700	7.2
M113 APC	TAERS	Road and Idler Wheels	225	8.2	3200	4.0
		Road, Idler and Suspension Hubs	224	8.2	3200	4.0
		Road and Idler Arms	83	3.0	8600	6.6
		Track Assembly	617	22.5*	1200	5.6
	VIETNAM	Road and Idler Wheels	46	16.3*	2200	3.0
		Road, Idler and Suspension Hubs	6	2.1	17200	3.0
		Road and Idler Arms	8	2.8	12900	3.2
		Track Assembly	14	5.0	7400	4.3
M113A1	TAERS	Road and Idler Wheels	53	32.9*	800	3.2
		Road, Idler and Suspension Hubs	2	1.2	22000	1.6
		Road and Idler Arms	5	3.2	8800	4.6
		Track Assembly	26	16.1	1700	6.2
	VIETNAM	Road and Idler Wheels	89	43.0*	700	2.9
		Road, Idler and Suspension Hubs	7	3.4	9400	2.0
		Road and Idler Arms	11	5.3	6000	3.0
		Track Assembly	19	9.2	3500	15.2

TAERS - Worldwide Army Equipment Reports
ACTIONS - Replacement, repair, or adjustment of a prime mobility component
MTBF - Mean time between failures
* - Highest of all components



M48A3 PRIME MOBILITY ACTION RATE



M113 ROAD AND IDLER WHEELS ACTION RATE

I[illegible]-me evident that the data could not be regarded as absolute fact as you might regard data taken from laboratory experiments. The TAERS data was reported by people whose knowledge of the subject was often minimal and whose interest was often low because this reporting was only one small element of their total responsibility. The knowledge and interest level of the reporters of the Viet Nam data on the other hand was of a high level. However, the Viet Nam data was taken in a combat situation which is vastly different from the non-combat situation for the TAERS data. Each of the four companies processed the raw data independently and "purified" and "interpreted" the data in the process.

The M48A3 vehicle prime mobility action rate curves illustrate these points. The upper curve is of TAERS data and the lower curve is of Viet Nam data. Note that the data points are much more scattered for the combat situation and the action rate is about three times as high at the 6000 mile life point on the curve. On the action rate curve for M113 road and idler wheels note that the action rate is four times greater in Viet Nam than in the TAERS curve. Considered with the additional fact that typically the average manhours per action are lower in Viet Nam than in TAERS data this indicates that the personnel took a greater personal interest in Viet Nam because their safety was very much involved. Under these conditions men will apparently be more critical in condemning a worn component and more energetic in replacing it. But also note in the tabular data that the MTBF for M113 track in Viet Nam was 7400 miles compared to only 1200 miles in TAERS data. Could it be that track was in short supply and therefore made to perform longer? This would seem to be confirmed by noting that the M113A1 experience was similar.

To aid in evaluating the above data it was compared with data extracted from another source - "Special Report on Roadwheels, Logistical Evaluation of Combat Vehicles, DA Study 17-66" shown on the next page.

MEAN TIME TO REPLACEMENT (IN MILES)

	M113	M113A1	M60	M48A3
CONARC	3676	2390	2450	2950
Europe	3450	NONE	3350	NONE
Vietnam	3950	3200	NONE	----

This M113 data shows somewhat longer roadwheel life than the TAERS data on Page 2. It also shows longer roadwheel life in Vietnam than in CONARC or Europe in contrast to shorter life shown in the previous data. The M113A1 data is more emphatically contradictory. Previous data show "life" 800 miles in TAERS and 700 miles in Vietnam - the table above shows 2390 miles in CONARC and 3200 miles in Vietnam. The report was studied in an effort to understand this contradiction. A statement in the "Logic" paragraph read, "It must be assumed that each failure is the first failure for a particular roadwheel as there is no reported distinction between roadwheels installed." In examining the detailed tabular data in the report it was found that there were no CONARC "A1" vehicles with over 5500 miles but some of the Vietnam vehicles had more than 7500 miles on them. By assuming that each failure is the first failure the additional miles on the vehicle increase the average wheel life and it is obvious that with 10,000 miles on the vehicles the life of the wheels would be still greater by this type accounting even if the wheels were failing every 100 miles. This report was deemed to be completely without value in this roadwheel study.

Some thought was given to initiating a special program to gather data for this study. This would be a very costly and time consuming project. A reading of the final report on "Run - Indefinite Test (Fort Carson, Colorado) Phase" gave convincing evidence that a special project is not likely to produce a better quality of data than might be available through other avenues. (See Appendix I.)

In spite of the faults with the data investigated it was considered adequate to show that roadwheels are a significant problem, accounting for probably 25% of all repair actions which affect mobility. But the data did not indicate the nature of the failure or the cause of the failure. Indeed some of the wheels replaced were undoubtedly serviceable and replaced by a worried combat soldier because it looked bad or replaced by a "spit and polish" officer under peace time conditions, but they were replaced.

Nature of and Cause of Failures - It was found that computerized data on EPR's (Equipment Performance Reports) was available from the System Performance Assessment Division of the Product Assurance Directorate. While this data only pertains to test track experience, it is considered the best source available to throw light on the nature of roadwheel failures. The data summarized covers roadwheel incidents which occurred during the sample period. The tests being conducted were not tests of roadwheels. The number of vehicles involved in the tests multiplied by the number of wheels per vehicle provided 600 of the M113 wheels and 1200 of the M60 wheels in the sample.

Roadwheel Failures	M113 (% of 600)	M60 (% of 1200)	M113% / M60%	Miles at Failure (Average) M113	M60
Bonding (Rubber)	12.3	2.3	5.3	2436	2735
Chunking (Rubber)	5.7	3.0	1.9	2432	2858
Worn (Rubber)	1.8	2.3	0.8	4154	5290
Broken Wheels	.7	0	---	3619	----
Bent Wheels	4.0	0		1855	----
Wear Plates	2.5	1.75	1.4	4470	3013

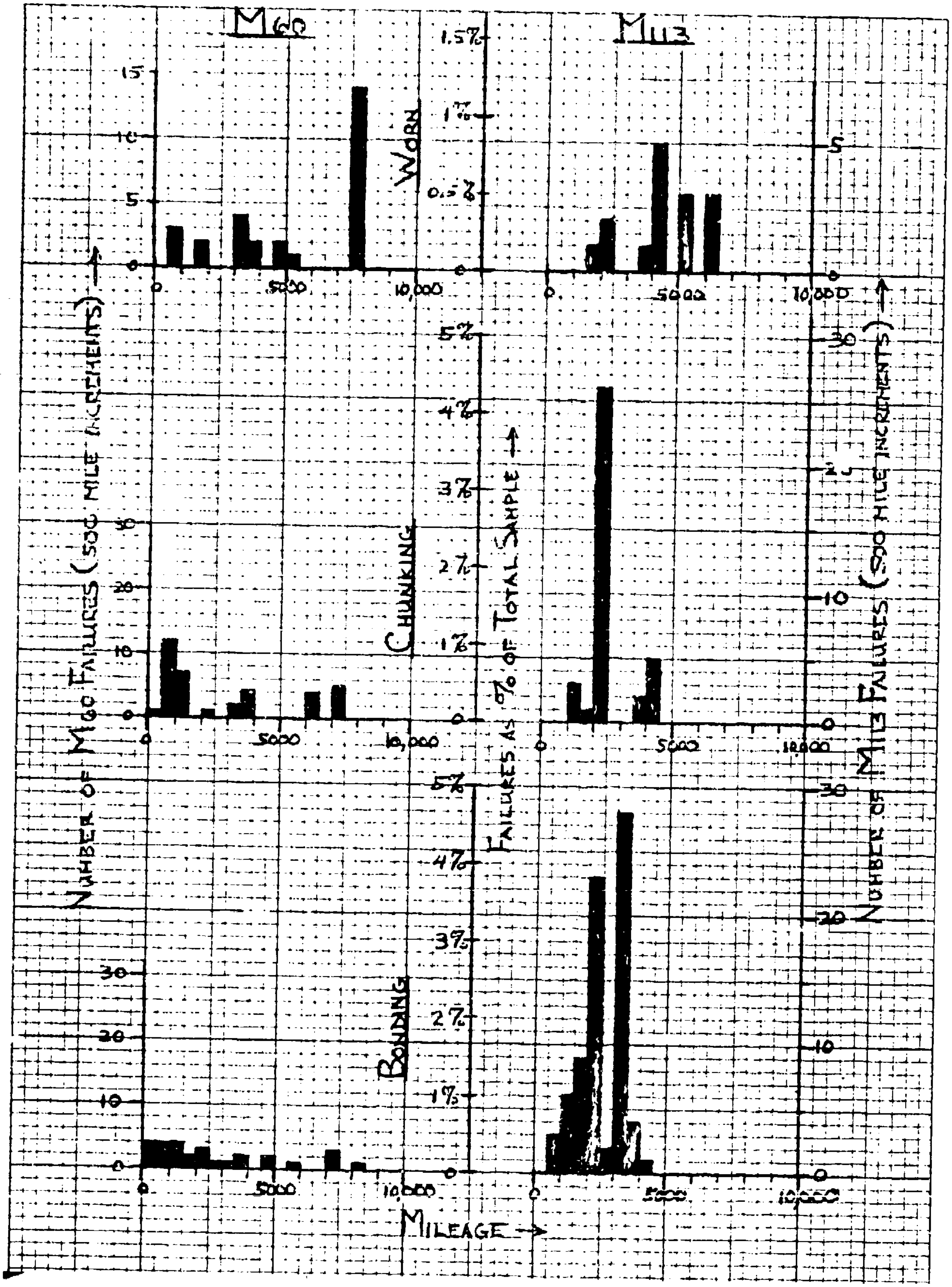
The failure rate of the M113 wheel is 2.9 times the failure rate of the M60 wheel. Bonding failures on the M113 are 5.3 times the rate on the M60. The M60 design provides a truly cylindrical surface for bonding of the rubber whereas the M113 wheel is formed plate and has rounded ends to the cylinder. The rounded ends mean that the load from the rubber is not transmitted by compression alone but also involves some shear. The construction of the wear plate on the M113 also induces bonding failures in contrast to the M60 construction. Note also that chunking failures on the M113 run 1.9 times the rate on the M60. This could be due to rubber being closer to the track center guide on the M113. The narrowness of the M113 tire may also be a factor. One might suspect that the testing was not comparable but the ratio of failures for worn rubber and wear plates indicates that the testing is quite comparable. It should also be pointed out that the poor showing of the M113 is in spite of much higher rubber specifications used on the M113 as shown below.

RUBBER SPECIFICATIONS	M113	M60
Durometer Hardness	70 $\pm$ 5	70 $\pm$ 10
Tensile Strength (minimum)	3000 psi	1900 psi
Elongation (minimum)	400%	200%
Adhesion	130 lb/in width	60 lb/in width

The rather high incidence of bent wheels on the M113 also indicates that a stronger basic wheel design is desirable.

The data was further analyzed by breaking the failures down to 500 mile increments of life. They are shown on the bar chart on Page 9. The roadwheel failures are broken down into bonding failures shown in the bottom section, chunking failures shown in the middle section, and worn rubber failures shown in the section at the top of the page. The M60 data is plotted on the left hand side and the M113 data on the right hand side of the page. The vertical scale at the center shows failures as a percent of the sample and is common to both the M60 and M113 data. The vertical scales at the sides of the page apply only to their respective data and are not common since there are 1200 wheels in the M60 data and only 600 wheels in the M113 data. From left to right the life of the wheels has been broken into 500 mile increments.

First, consider the two bar charts on bonding failures. Note that the failure rate on the M60 is constant in the first three 500 mile increments and then generally declines. Now note that on the M113 there were no failures in the first 500 mile increment but then the pattern is one of steeply rising failures


M60
M113
Worn
Chunking
Bonding
Number of M60 Failures (500 Mile Increments) →
Failures as % of Total Sample →
Number of M113 Failures (500 Mile Increments) →
Mileage →
0
5000
10,000
1.5%
1%
0.5%
5%
4%
3%
2%
15
10
5
30
20

in succeeding increments. The difference in pattern is striking! But why? Remember the rubber specification is much more restrictive on the M113 - especially with regard to adhesion. Past experience indicates that rubber processing is especially dependent on personal attention to detail for the maintenance of quality. Given these conditions, a supplier would naturally concentrate more personal attention on the M113 wheel than on the M60. As a result, one might receive a higher percentage of M60 wheels containing flaws such as foreign materials present on bonding surface, bare spots on rim which had been missed when applying bonding compound, improperly cleaned rim surfaces, etc., than would be found on M113 wheels. As the wheels were put into service these flaws would result in early failures, but as these wheels were thus eliminated the balance of the wheels would perform in accordance with design conditions. On this assumption, the M60 design appears to provide good resistance to bonding failures.

The M113 wheel, on the other hand, if it received special attention to meet the high quality requirements, would perform better in the initial 500 mile increment. Then as the effects of the additional shear stresses designed into the M113 wheel built up with each mileage increment one would expect the failure rate to increase as it does on the bar chart.

Chunking failures are less regular because they may be caused by track center guides digging into the rubber tread due to track twisting over rocks or misguiding in sharp turns and then pulling back into the proper position. Also stones and rocks may get squeezed between the track and the roadwheel and thus cut deeply into the tread rubber. However, chunking is still somewhat related to rubber deterioration and rubber quality. The bar charts bear out this relationship even if irregularly.

The bar charts on worn rubber are still less regular but do also show something of a pattern with less failures in early 500 mile increments on the M113 due probably to the higher strength rubber specification. It is interesting though to note that the advantage disappears in later increments of mileage. At 5000 miles, 1.08% of the M60 wheels had failed whereas 1.5% of the M113 wheels had failed. By 6500 miles, the comparison is 1.17% for the M60 and 2.5% for the M113. There was no data for the M113 beyond 6500 miles but it is interesting to note that at 8000 miles the failure rate for worn rubber on the M60 was still only 2.33% compared to 2.5% for the M113 on 6500 miles. It does appear that the advantage of higher rubber specifications for the M113 was lost after 4000 miles.

Concept to Correct Problem - A decision was made to try to correct the troubles on the M113 wheel. It was felt bonding failures were due to human failures in quality control and to the shape of the rim. The human failures probably could not be corrected for more than a short period at a time. There would be resistance to changing the shape of the rim because it was inexpensive to make. Chunking failures were the results of track guides getting into the wrong place and of the miserable environment in which the vehicle had to operate. These conditions could not be changed. But suppose some "armor" was put around the rubber tire? This could keep track guides and stones from cutting into the rubber tire. Also if the rubber tire was compressed between the aluminum wheel rim and the "armor", which would be a steel ring, the mechanical separation of the rubber from the aluminum rim could not occur. Thus the bonding failures would be thwarted. A flange could be folded down to serve as the wear surface for the track guides. This would provide better track guide control than the present design and this flange could extend far enough down to provide a slightly smaller inside diameter than the outside diameter of the aluminum wheel rim so that there would be a mechanical interference to prevent any tendency to push the steel ring and rubber off to the side. Of course, there would be disadvantages. This would add undesirable weight to the wheel and it would stiffen the ride some. Also there was no background of experience to help design such a wheel. Using general design experience, the wheel was designed using ¼" thick steel for the shroud and the standard M113 aluminum roadwheel except for omitting the steel wear ring. The wheels were sent to the supplier who contracted to make the steel shroud and the rubber and assemble the unit. Twenty-four wheels were purchased. Strikes and material shortages caused a long delay but the wheels were finally delivered.

TESTING OF THE WHEELS

Ride Quality Changes - Each of the 24 wheels was stamped with a number and then striped with paint so any possible creep of the tire could be determined. The vehicle was instrumented with three accelerometers to measure vertical acceleration at the front end of the vehicle, at the drivers seat, and at a point on the floor of the vehicle vertically below the center of gravity. Bags of lead shot were added to the crew compartment to increase the weight. The GVW as tested (with track end covers and track shrouds removed) was 22,874 pounds. Runs were made over the dirt test track adjacent to Building 219 and over the four 3" bumps at 16' centers, the five 6" bumps at 20' centers, and the five 8" bumps at 20' centers. Runs were made at 5, 10, 15, 20, and 25 mph to the extent possible with safety and each course was run in each direction. Each test was performed again with standard wheels for comparison. The results are shown in the tables appearing on the following pages.

ACCELERATIONS IN G's OVER 3" BUMP COURSE

STANDARD WHEELS							STEEL SHROUDED WHEELS						
		E			W				E			W	
MPH	F	DR	CG	F	DR	CG	MPH	F	DR	CG	F	DR	CG
5	1	½	½	1	½	½	5	1½	1	½	1	½	½
	1	½	½	1	½	½		1½	1	1	1½	1	1
	1	½	½	1	½	½		1½	1½	1	1½	1	½
	1	½	½	½	½	½		1	1	½	1	1	½
10	2½	2	2½	1½	1½	1½	10	2	1½	1½	2	2	2
	3	2½	3	4	3½	3		1½	2	1½	2	2½	2
	1½	1½	1	1½	1½	1		1½	2	2½	1½	2½	2½
	1	½	½	1½	1	½		2	2½	2	2	2	2½
15	1½	1½	1½	2½	2½	3	15	2½	2½	2½	3	3	3
	3½	3½	3	1½	1	1		3	2	2½	4	3	3½
	3½	4½	4	2½	1	1		5	3	3	5½	3	3½
	2	2½	2½	1	1½	1½		5½	3½	3	4	3½	4
20	3½	2½	2½	4	4	3½	20	6	3½	3½	6½	4	4½
	3½	3½	3	3½	3	3		6	3	3	4	3	4
	2	2	1½	2½	3½	3		5½	3	4	4	4	3½
	1½	1	1	3½	3	3½		5½	4	4	6	3½	5
25							25	4	4	6½	5½	5	7
								4½	4½	4½	5½	4½	7½
								4	5	6	5½	3½	4½
								4½	4	5	7	3½	4½

ACCELERATIONS IN G's OVER 6" BUMP COURSE

	STANDARD WHEELS							STEEL SHROUDED WHEELS					
		E			W				E			W	
MPH	F	DR	CG	F	DR	CG	MPH	F	DR	CG	F	DR	CG
5	2½	2½	2½	3	3	3	5	2	1½	1	3½	2½	2
	3	2½	3	2½	2½	3		2	1½	2½	2	2	1
	2	1½	2½	2	2	2		2	1½	1½	2	2½	2
	1	½	½	3	2½	2		2	1½	1½	2½	2	1½
	1	1	2	1½	1½	1		4	3½	2	2½	2½	1½
10	2½	2½	2½	2½	2½	2	10	2½	2	2	3	2½	2½
	2	3	1½	2½	2	2		2	1½	1½	2½	2	2½
	3	3	3	3½	4	3½		2½	2	3	3	2½	2
	2	1½	1	3	2½	2½		2	2	1½	3	2½	2½
	3	3	3½	2½	2	2		2½	2½	1½	3	3	2½
15	12½+	10½	8				15	3½	3½	3	4	3	4½
	12½+	11½	7½					3½	4½	3	4	4	5
								4½	3½	4½	7	6	5½
								4½	3½	3½	12½+	12½+	10½
								4	5½	3½	12½+	10½	10½

ACCELERATIONS IN G's OVER 8" BUMP COURSE

	STANDARD WHEELS							STEEL SHROUDED WHEELS					
		E			W				E			W	
MPH	F	DR	CG	F	DR	CG	MPH	F	DR	CG	F	DR	CG
3	2½	1½	3	2	2	3	3	2	2	2	3	3	4
	4	1	4½	2	4½	4½		2½	1	3	2	3	3
	3½	1	4½	2	2	2½		3	1½	3½	3	3½	3
	1½	1	2	2	2	2½		6½	2½	6½	2	1½	3
	2	1	2½	1½	2	3		2½	3	4	4	2	5

For better understanding, the data have been condensed by averaging and are shown below.

ACCELERATIONS IN G's OVER DIRT TRACK

STANDARD WHEELS					STEEL SHROUDED WHEELS				
MPH	F	DR	CG	AVRG	MPH	F	DR	CG	AVRG
5	.5	.5	.2	.4	5	1.0	1.5	1.0	1.2
10	.5	1.0	.5	.7	10	2.0	2.5	2.0	2.2
15	1.5	2.0	2.0	1.8	15	2.5	3.0	2.5	2.7
20	1.5	1.5	1.5	1.5	20	3.0	3.0	3.0	3.0
25	1.5	1.5	1.5	1.5	25	3.5	3.5	3.0	3.3

ACCELERATIONS IN G's OVER 3" BUMPS

STANDARD WHEELS					STEEL SHROUDED WHEELS				
MPH	F	DR	CG	AVRG	MPH	F	DR	CG	AVRG
5	1.0	.5	.5	.7	5	1.3	1.1	.7	1.0
10	2.1	1.7	1.6	1.8	10	1.8	2.1	2.1	2.0
15	2.2	2.2	2.2	2.2	15	3.9	2.9	3.1	3.3
20	3.0	2.8	2.6	2.8	20	4.7	3.5	3.9	4.0
25					25	5.1	4.2	5.7	5.0

ACCELERATIONS IN G's OVER 6" BUMPS

STANDARD WHEELS					STEEL SHROUDED WHEELS				
MPH	F	DR	CG	AVRG	MPH	F	DR	CG	AVRG
5	2.2	2.0	2.2	2.1	5	2.4	2.1	1.7	2.1
10	2.6	2.6	2.4	2.5	10	2.7	2.3	2.2	2.4
15	12.5	11.0	7.8	10.4	15	6.0	5.6	5.4	5.7

ACCELERATIONS IN G's OVER 8" BUMPS

STANDARD WHEELS					STEEL SHROUDED WHEELS				
MPH	F	DR	CG	AVRG	MPH	F	DR	CG	AVRG
3	2.3	1.8	3.2	2.4	3	3.0	2.3	3.7	3.0

The following table of Amplification Factors shows the factor by which the average "G" reading of the vehicle with standard wheels would have to be multiplied to get the average "G" value of the vehicle with steel shrouded wheels. It is an index of the change in ride quality with low numbers being favorable.

AMPLIFICATION FACTORS

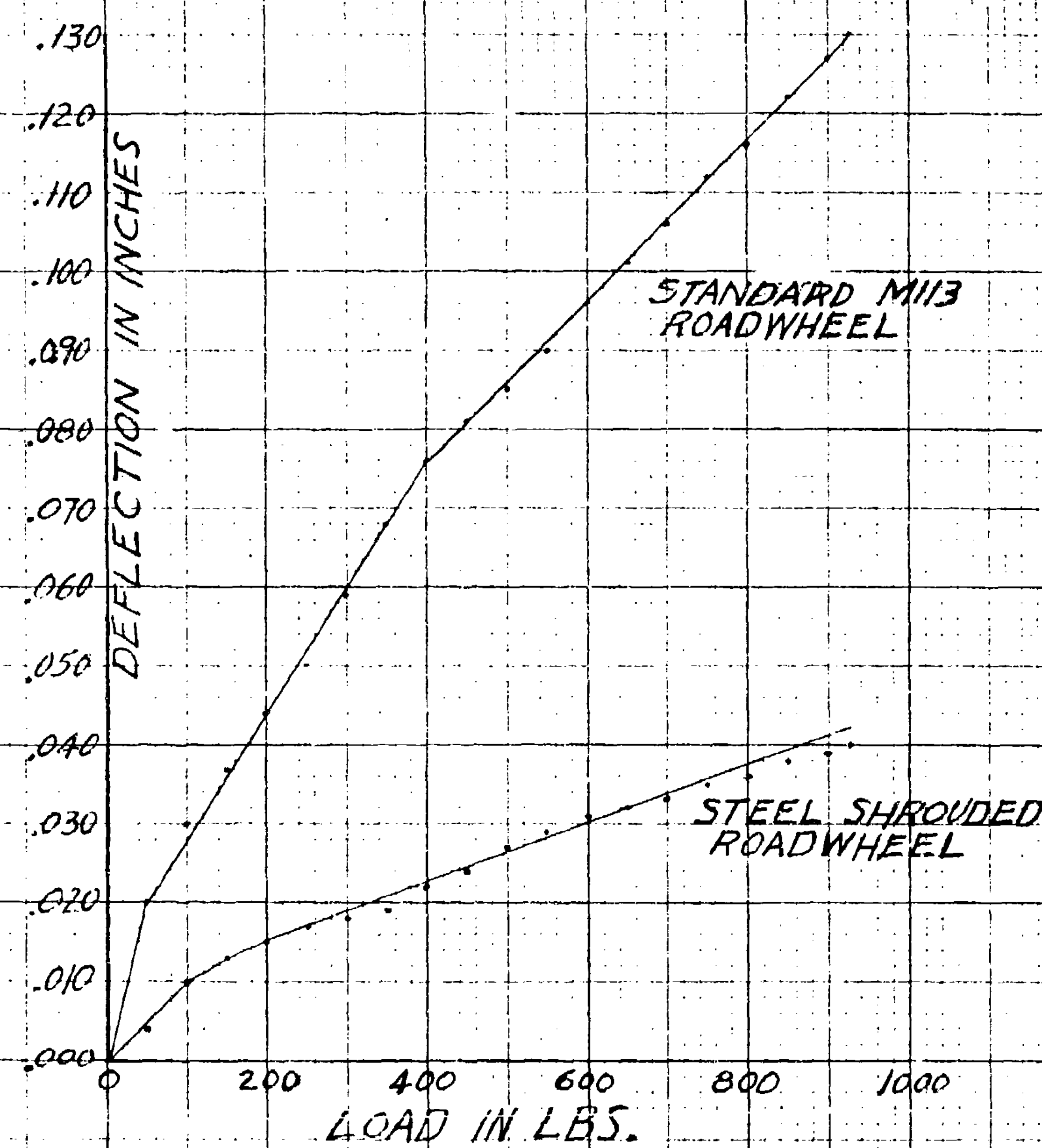
MPH	3" BUMP	6" BUMP	8" BUMP	DIRT TRACK
5	1.4	1.0	1.3	3.0
10	1.1	1.0		3.1
15	1.5	.5*		1.5
20	1.4			2.0
25				2.2

*Insufficient Data

Note that the 3.0 factor for the dirt track at 5 mph does not mean that that ride is more harsh than the dirt track at 20 mph which has a factor of 2.0. But it does mean that as a change is made from standard wheels to steel shrouded wheels, the ride quality deteriorates more at 5 mph than at 20 mph on the dirt track.

Load-deflection data was taken in the laboratory on the steel shrouded wheel and on the standard M113 wheel. The curves have been plotted for comparison. The objective was to see if load deflection data could be used in lieu of vehicle field tests to indicate probable ride characteristics. In this respect it is interesting to note that the load deflection curves show the

LOAD DEFLECTION CURVES



steel shrouded wheel to be three times as stiff as the standard wheel. For low speeds on the dirt track, the Table of Amplification Factors shows the same magnitude of increased stiffness. It should be remembered that the tire is only one of the springs. The other spring is the vehicle suspension spring and these two springs are in series. The accelerometers recording ride quality are of course on the vehicle hull. It is felt the correlation shown for low speed on the dirt track is significant. If this would prove to be true on several more tests it would be a valuable tool and could save much cost by making full vehicle field tests less necessary in evaluating wheel candidates.

Noise Level Changes - The Research Function of the Engineering Science Division has measured the noise level both inside and outside the M113 Armored Personnel Carrier for standard roadwheels and for steel shrouded roadwheels. The results are summarized below. Further details are available in USATACOM Report Number 11971.

Paved test track data indicate the total noise (the linear weighted readings) inside the vehicle decreased slightly when the roadwheel modification was applied. The A weighted (dB(A)) data, however, increased slightly when the vehicle was operated with the modified roadwheels. This is because the A weighted readings boost the 1/3 octave bands in the 1000 to 4000 HZ region and attenuate the 1/3 octave bands below 500 HZ and above 5000 HZ. Since MIL-STD-1474, the Army standard pertaining to military vehicle noise and most non-military industrial and transportation noise standards utilize A weighted spectrum for their noise criteria, the dB(A) levels given in the tables should be utilized as the factor for determining any increase or decrease in vehicle noise.

The interior noise measurements indicate that when the vehicle was operated on a dirt track, both the A weighted and unweighted levels were less for the modified version.

Unweighted and A weighted noise levels on the exterior of the M113 were consistently higher for the modified vehicle. Noise level increases varied from 3 dB(A), with the vehicle operating on the dirt course at 5 mph, to 11 dB(A) at 15 mph on the paved track. The noise level increase was most pronounced in the 1/3 octave bands above 400 HZ. Although the direction of the exhaust slightly affected the noise levels recorded, the increases in noise level of the modified vehicle over the unmodified version were consistent with the exhaust toward or away from the microphone.

The addition of steel banded roadwheels to the M113 did not appreciably affect the vehicle's interior noise level, but did increase the exterior noise level an average of 6.7 dB(A) under all operating conditions. Most of this increase was in the high frequency portion of the noise spectrum.

It should be pointed out that the rubber track pads on the roadwheel side of the track did not project above the steel portions of the track shoe at each end of the rubber and we therefore had the steel shroud on the wheel contacting the steel of the track shoe between the rubber pads. This was a cause of much of the added noise. If it seemed otherwise worth going to steel shrouded roadwheels, it is felt much could be done to reduce this increased noise by so designing the track as to prevent this steel to steel contact.

Lock rings were included in the design of the steel shrouds to insure against the steel shroud working its way off the rubber tire sideways. There was no bonding between the steel and the rubber, but the rubber was bonded to the aluminum inner wheel. The first lock ring came off as the vehicle was being moved within the shop. By the time the runs on the bump course and for noise level measurements were finished, thirteen of the twenty wheels had lost the lock ring.

Durability Tests - The durability tests were conducted at General Motors Proving Ground, Milford, Michigan between 23 Jan and 25 Feb 75. Temperatures varied between 4° and 45°F. The track condition varied from frozen to sloppy and slippery - often within the same day. A typical day of testing consisted of 40 miles on gravel roads at 20 to 30 mph, 40 miles of medium cross-country at 20 to 30 mph, and 20 miles of rough cross-country at

5 to 15 mph. Each of the steel shrouded wheels had been stamped with a number (1 to 24). The first 20 were assembled on the vehicle and four were left as spares. None of the steel shrouded wheels appeared to have suffered any damage in the bump tests or the noise level tests. As a wheel failed, it would be replaced by a spare. If there were no spares, then the broken wheel and its mate would both be removed and replaced by standard wheels. The unbroken wheel would become a spare. The wheels are listed below by number. "F" indicates failure, and "R" removed. The total mileage accumulated on the wheel is also shown.

WHEEL NUMBER	"F" or "R"	MILES
1	F	690
2	cracked	998
3	F	628
4	R	746
5	F	518
6	F	373
7	F	249
8	F	777
9	R	1116
10	R	1116
11	R	1037
12	F	1037
13	F	998
14	R	1116
15	F	895
16	F	895
17	F	998
18	F	777
19	F	249
20	F	302
21	F	441
22	F	705
23	F	160
24	R	743

These mileages have been rearranged to provide a feel for the failure rate vs mileage.

MILES	"F" or "R"	
160	F	
249	F	
249	F	
302	F	
373	F	
441	F	
518	F	
628	F	
690	F	
705	F	
743		R
746		R
777	F	
777	F	
895	F	
895	F	
998	F	
998	F	
998	cracked	
1037	F	
1037		R
1116		R
1116		R
1116		R

The test was stopped at this time while there were still several unbroken wheels which could be studied to see if cracks had started and if so, possibly provide a clue as to the mechanism of failure.

The data was also rearranged in still another form shown on the next page. Each wheel position on the vehicle is shown along with each wheel number used at that wheel position and the mileage accumulated by that wheel number at the wheel position. Also shown is whether the wheel failed or was removed for other cause. The average mileage of the failed wheels is also shown in parenthesis for each position and the number of failures following the parenthesis, but this does not include their mileage at other positions.

WHEEL POSITIONS ON VEHICLE

FRONT

LEFT		POSITION	RIGHT	
OUTSIDE	INSIDE		INSIDE	OUTSIDE
#12-1037-F STANDARD	#11-1037-R STANDARD		#1-690-F STANDARD	#2-690-R STANDARD
(1037)-1		1	(690)-1	
#14-1116-R	#13-998-F # 4-118-R		#3-628-F STANDARD	#4-628-R STANDARD
(998)-1		2	(628)-1	
#16-895-F STANDARD	#15-895-F STANDARD		#5-518-F #22-598-F	#6-373-F #24-743-R
(895)-2		3	(496)-3	
#18-777-F #2-221-R* STANDARD	#17-998-F STANDARD		#7-249-F #21-441-F #2-87-R STANDARD	#8-777-F STANDARD
(887)-2		4	(489)-3	
#20-302-F #22-107-R STANDARD	#19-249-F #23-160-F STANDARD		#9-1116-R	#10-1116-R **
(237)-3		5		

*cracked
** See Appendix II, Figure 3

Note that it would be a mistake to assume that the vehicle weight and related dynamic loads are distributed rather evenly over the twenty wheels. The failure chart shows a very definite pattern and extreme differences between wheels. The left rear wheel receives the most abuse with three failures averaging 237 miles each. Then the next most abused wheel is the number four right with three failures averaging 489 miles each. The average mileage at failure increases as one moves forward on the right side of the vehicle. This progression continues as one shifts over to the number four left wheel and moves forward. But from the number one left wheel, the progression shifts to the number five right wheel as the least abused wheel position on the vehicle with no failures in the total of 1116 miles. There is more than a four to one ratio between the average life of the most abused wheel and the average life of the wheel that is next to the least abused.

Obviously the wheel designer is faced with a serious problem. He is required to design a wheel that will have high reliability and long life so the vehicles will have high reliability and availability. A commander would not require an unduly large fleet of vehicles because a high percentage were deadlined at any time. But if the wheel designer designs to suit the left rear wheel, the wheel may be considered overly expensive and possibly heavy for other positions. Logistical considerations make it unreasonable to consider several different wheel designs for different positions on the vehicle.

It is suggested that a study be made to see if this pattern exists for standard M113 wheels. Then it is suggested that the vehicle designers consider the situation. It is realized they stagger the roadwheels from right side to left side to suit torsion bars, vary the wheel spacing to prevent all wheels from bumping on track block joints at the same time, place the engine at the right front corner, etc., for good reasons, but it could be that roadwheels now must play a more important part in the various compromises.

Returning to the evaluation of the steel shrouded wheel, approximately eight wheel samples were sent to the metalurgist for examination. Some of these wheel samples were unfractured and others fractured. One had a crack just starting on the inside diameter of the steel shroud flange. The metalurgical report is included in Appendix II.

An attempt had been made to get engineering data from rubber companies for use in the design of this steel shrouded roadwheel without much success, until one representative said his company had considerable experience in similar assemblies, particularly a shock absorbing drive shaft on a submarine. Also, he mentioned that a builder of logging equipment was at that same time doing something similar on a roadwheel but they were using a steel ring twice as thick. The ring was purposely being kept as thin as it was felt could live to keep the wheel weight down - .187 inch had been considered, but .250 inch was selected. Rather than supply data, the supplier countered by providing a proposal to supply the wheels and a drawing to show what had been discussed. Avoiding welding in the steel ring, possibly by spinning it from thin plate, had been discussed, but was not spelled out. There were many delays due to a strike, material shortages, and difficulty with suppliers and it is likely that this small order did not get adequate attention. The matalurgist believed the ring was welded and the supplier finally confirmed this as shown in Appendix III. A ring forging would be a suitable method of producing the ring with subsequent machining. However, the method used was not satisfactory and the failures occurred at the weld.

It should be noted that the retaining rings were useless and lost quickly. However, there were only a couple of wheels where any tendency of the steel ring to work off the rubber was noted and in those cases, it was so slight that it was not definite. There was no creep of the steel ring around the circumference of the wheel. Subject to confirmation by further testing, it is concluded that retaining rings are not needed.

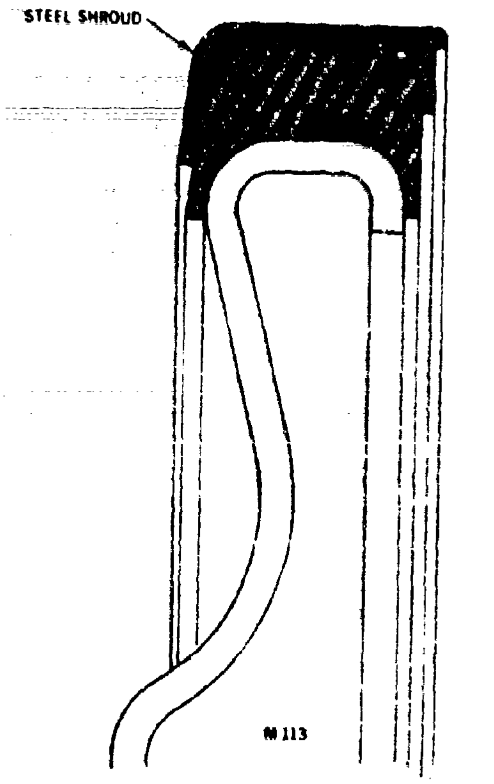


FIGURE 1 - Concept of Steel Shrouded Roadwheel

FIGURE 2 - Wheel Components and Finished Wheels

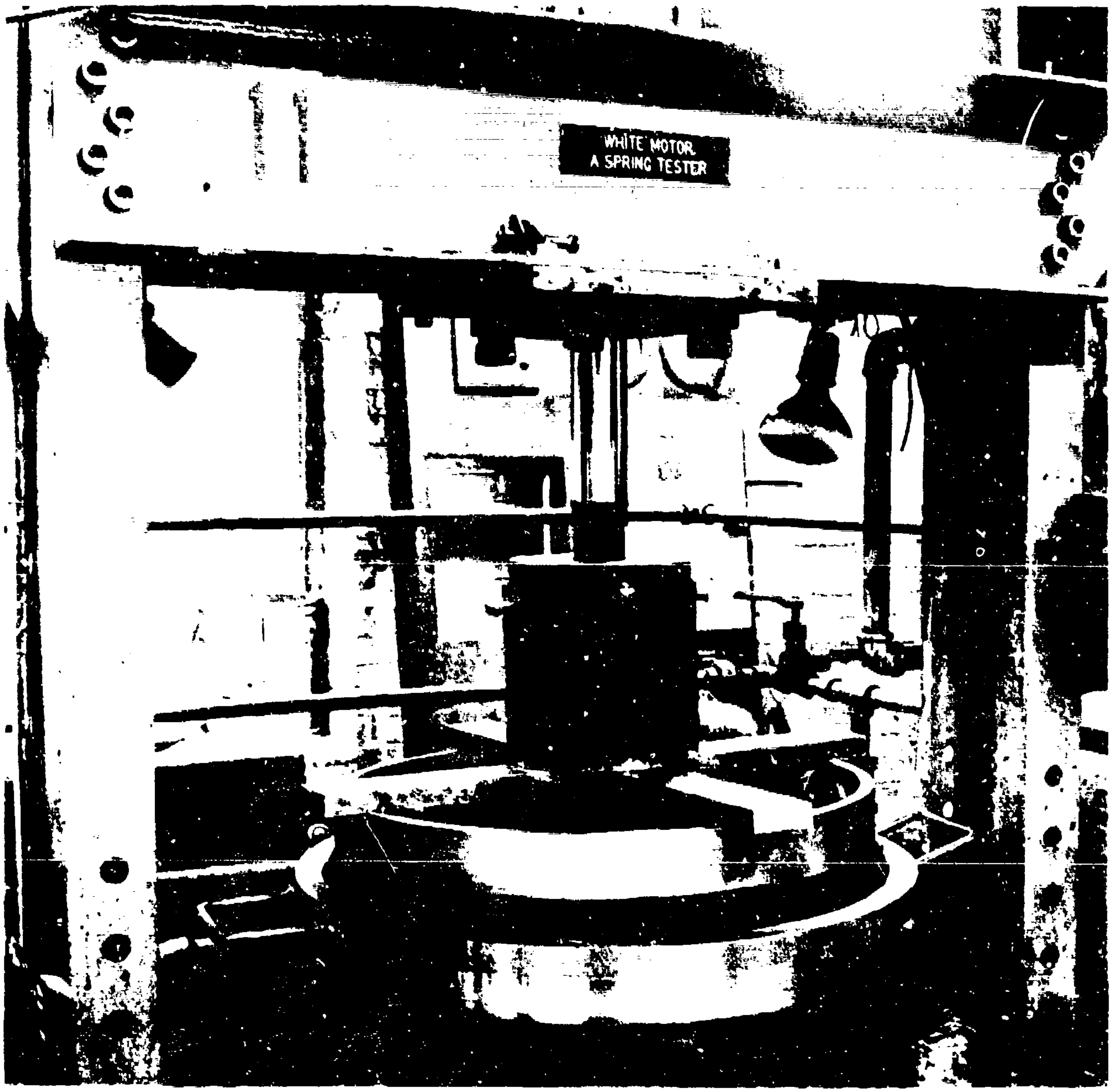
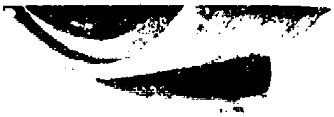


FIGURE 3 - Pressing Wheel into Shroud

FIGURE 4 - View from Retainer Ring Side



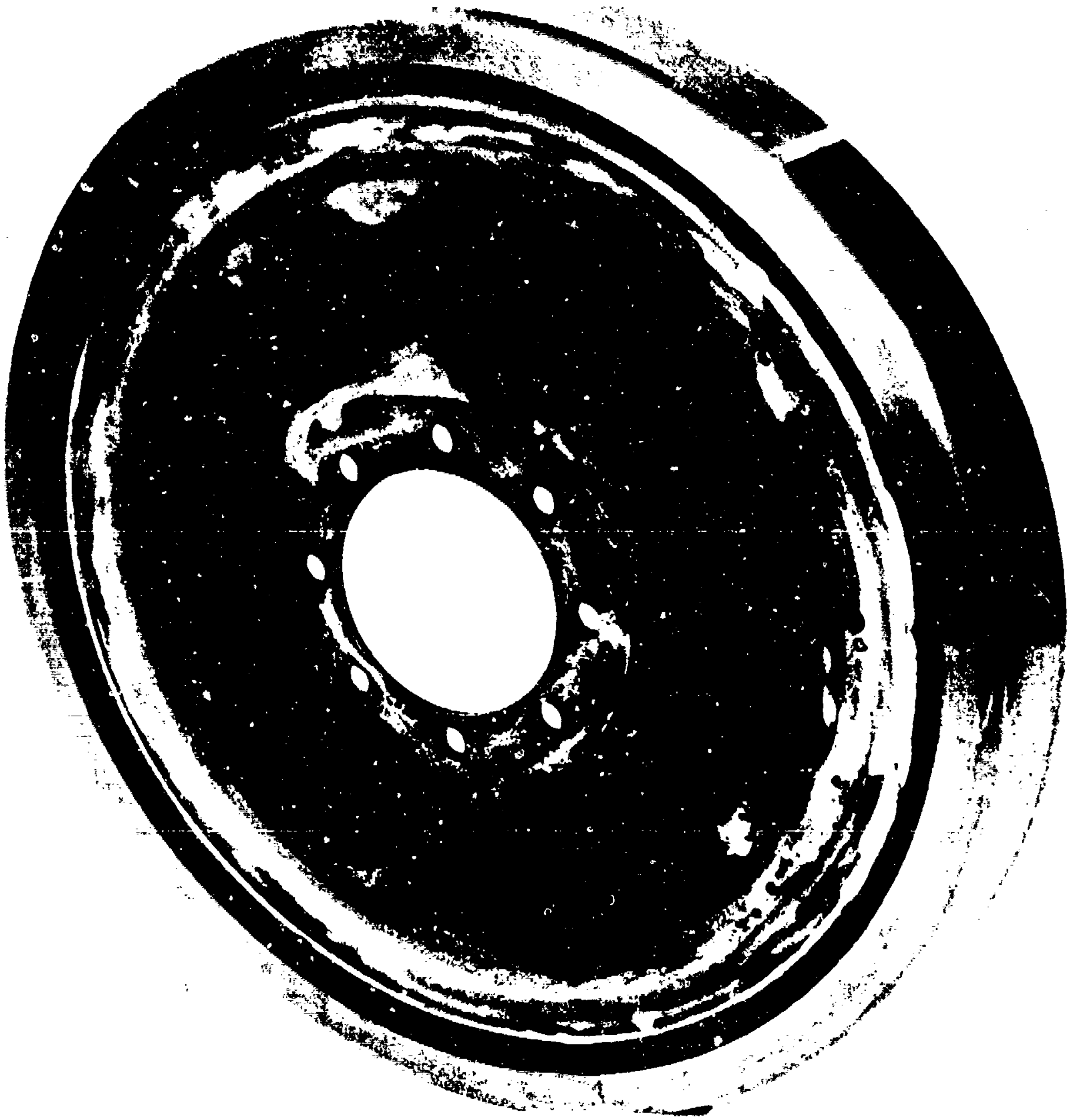


FIGURE 5 - View from Flange Side

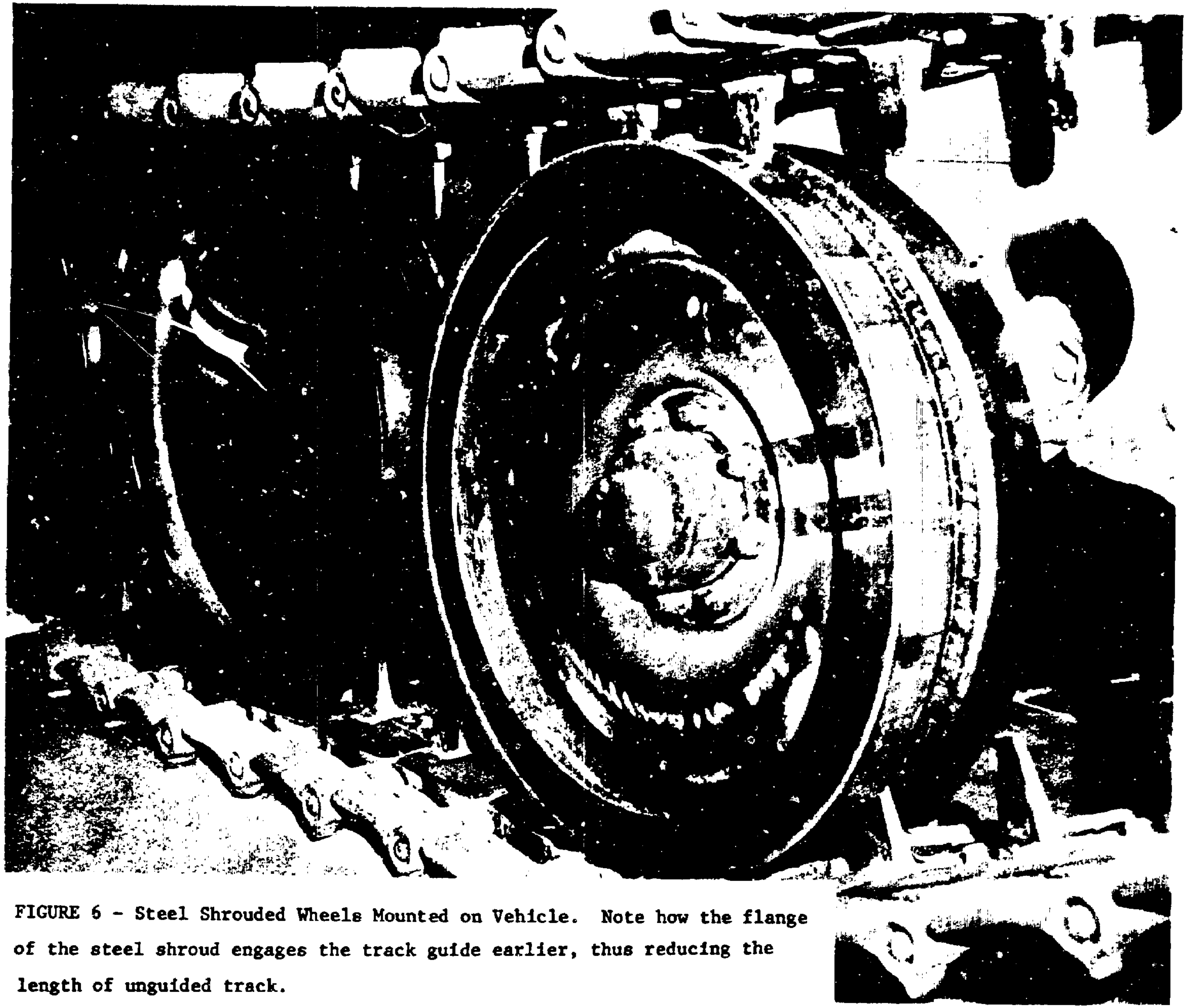


FIGURE 6 - Steel Shrouded Wheels Mounted on Vehicle. Note how the flange of the steel shroud engages the track guide earlier, thus reducing the length of unguided track.

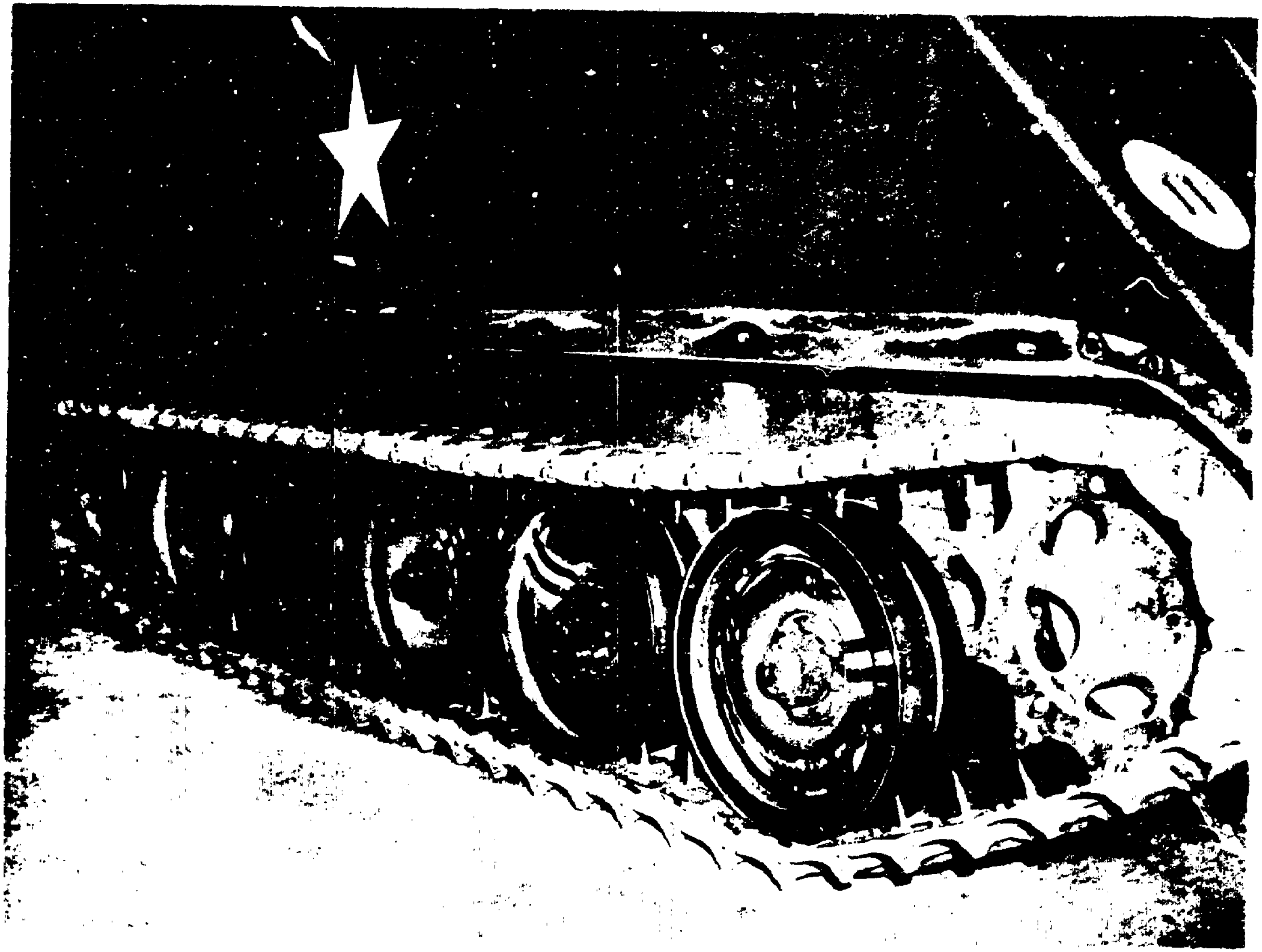


FIGURE 7 - Wheels Mounted on Vehicle

FIGURE 8 - Intact Wheels After Test. Mileages From Left to Right: 1037 Miles, 743 Miles, and 1116 Miles.

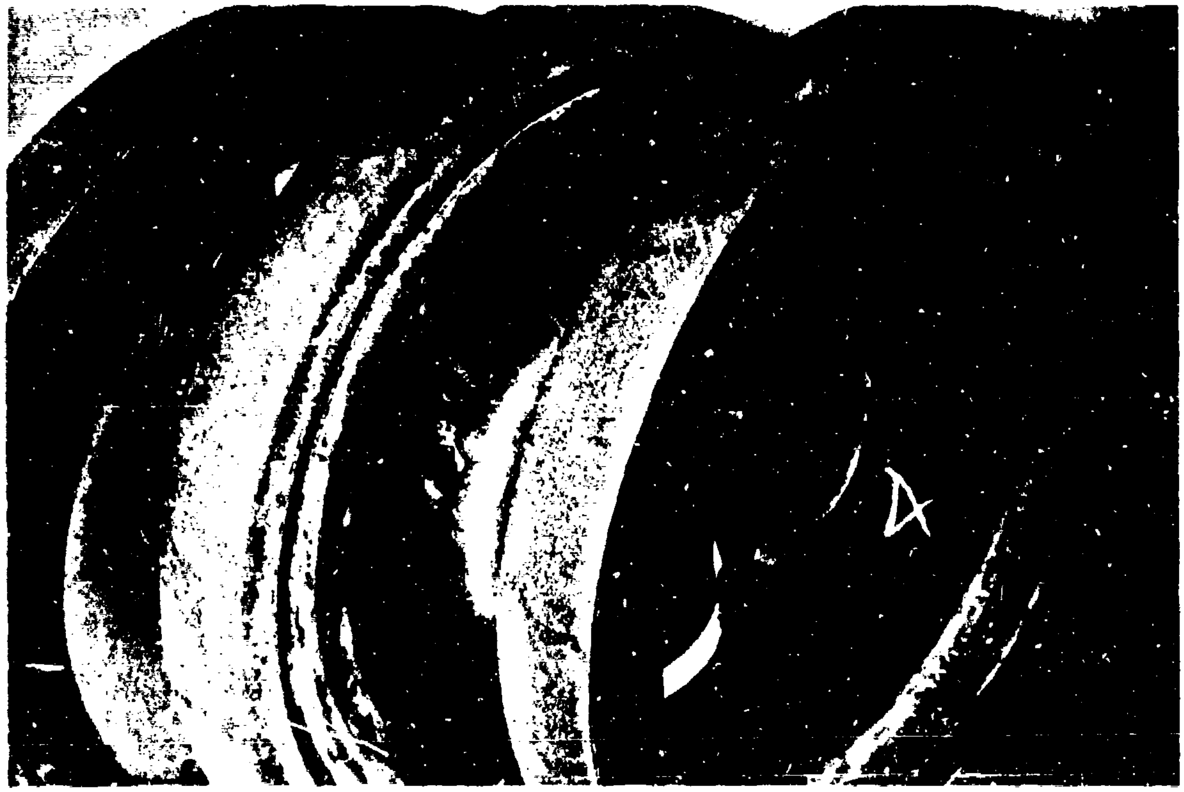


FIGURE 9 - Intact Wheels After Test. Mileages From Left to Right: 1116 Miles, 1116 Miles, and 746 Miles.

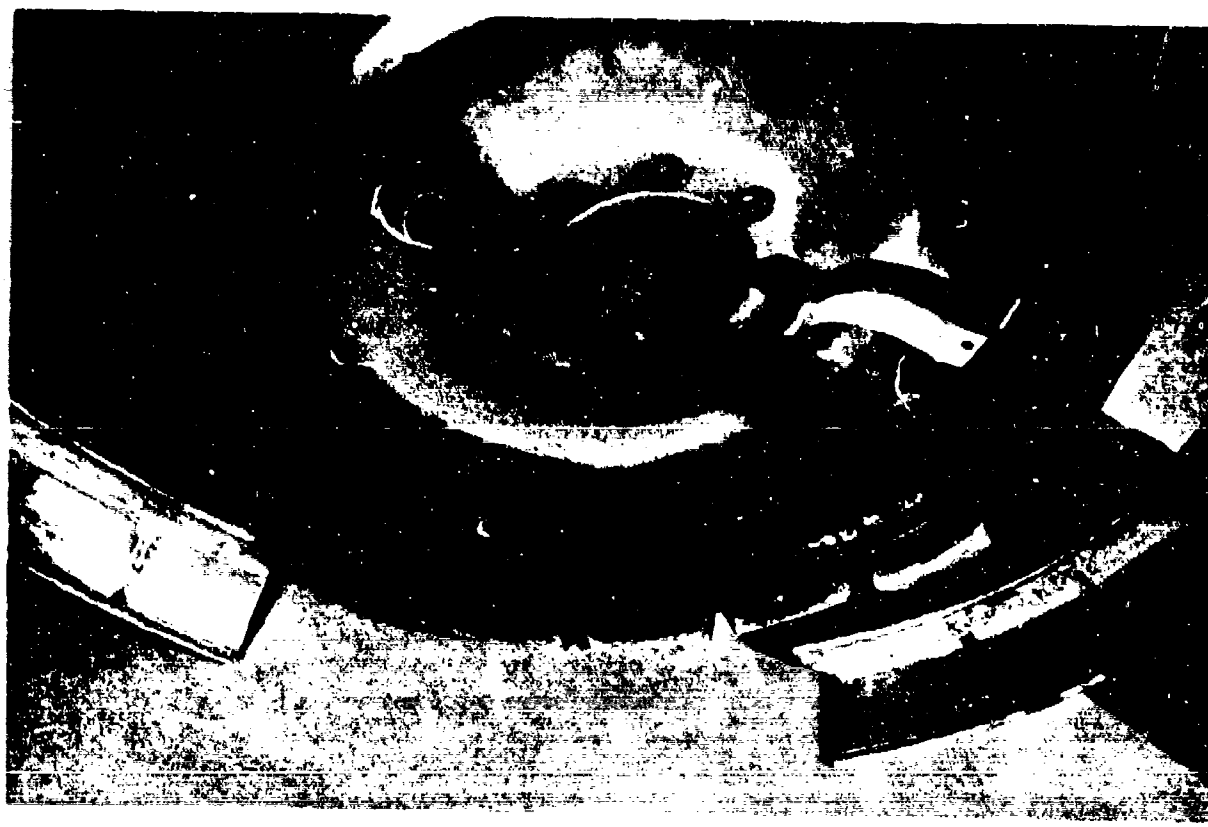


FIGURE 10 - Failed Shroud and Related Wheel

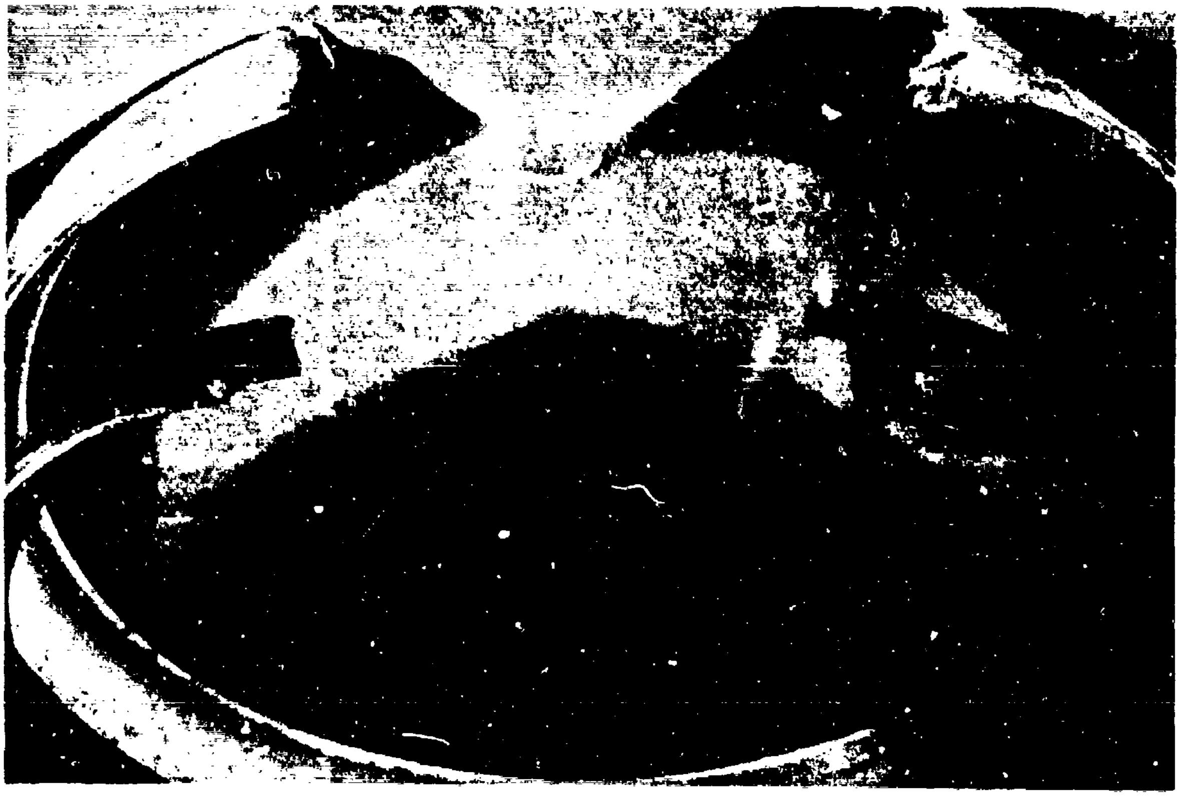


FIGURE 11 - Two Additional Failed Shrouds

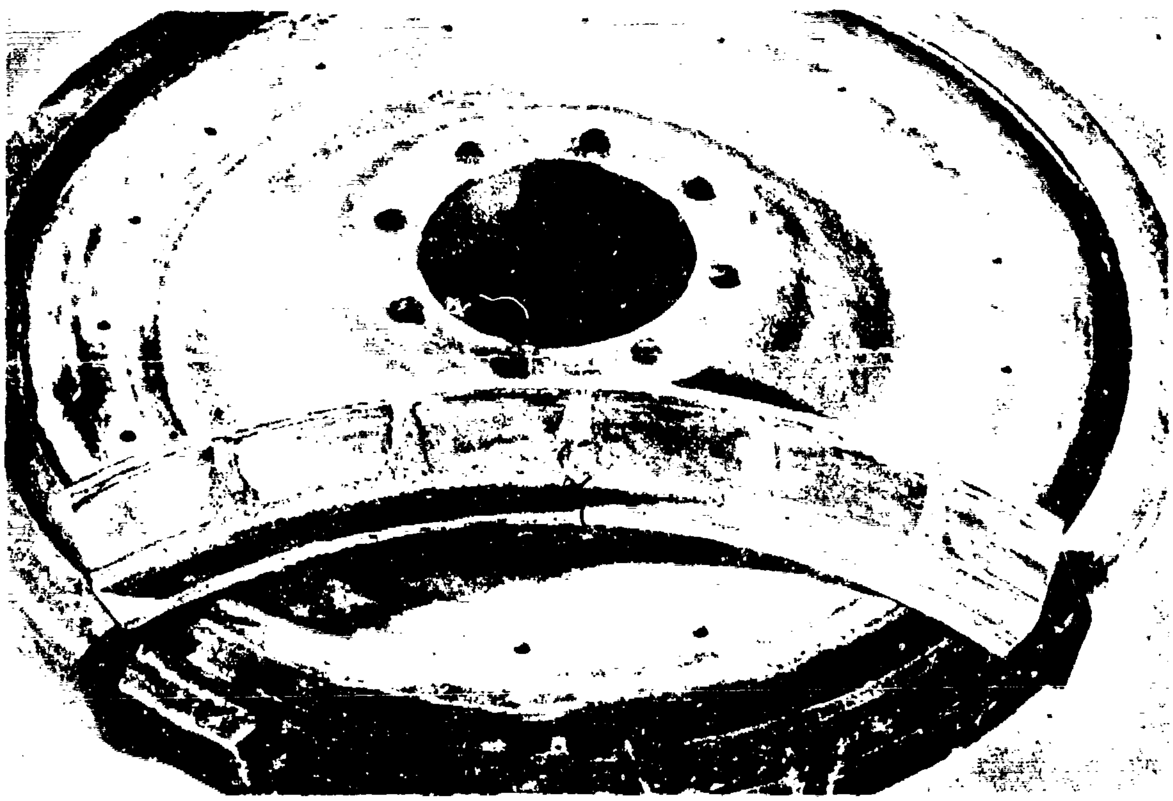


FIGURE 12 - Wheel #2 on Which Shroud Was Cracked but Still Not Broken After 998 Miles. Section Was Sawed From Shroud to Study Crack.

APPENDIX I

EXCERPT FROM FINAL REPORT ON "RUN-INDEFINITE TEST (FORT CARSON, COLORADO, PHASE)"

2. HISTORICAL BACKGROUND

2.1. Concept Phase.

2.1.1. In 1961, the Department of the Army (DA) formally recognized the requirement to develop a realistic overhaul policy for combat vehicles. At that time, research revealed that no specific records or historical data were available to statistically support or establish a firm policy.

2.1.2. Evaluation teams were dispatched to the US Army Europe/ 7th US Army (USAREUR) and its support depots. Specifically, these teams were to analyze:

2.1.2.1. The need, it any, for depot overhaul.

2.1.2.2. The mileage of vehicles currently in overhaul programs.

2.1.2.3. The standards employed to determine if an overhaul requirement existed.

2.1.3. No specific turn-around time was being utilized and several different standards were in use. Consequently, the effectiveness of the overhaul program could not be measured with any degree of certainty. As a result, a series of three tests were devised using M60 Combat Tanks and M113 Personnel Carriers.

2.2. European Phase.

2.2.1. A letter of agreement was drawn up between DA and USAREUR and a contract was awarded to the Research Analysis Corporation (RAC) to collect the required data and to, subsequently, recommend the parameters for a combat vehicle policy.

2.2.2. One of the three tests involved operating fifty (50) M113 carriers on a run-indefinite test, supported solely by Organizational and field maintenance, (It was later decided that 10,000 miles per vehicle would satisfy the run-indefinite requirements.)

2.2.3. This test ran from July 1961 through June 1964 with RAC monitoring the data generated. RAC's contract was not renewed for fiscal year 1965 and, in August 1964, DA requested the Army Materiel Command (AMC) conduct the remainder of the tests on an in-house basis. This study was assigned to the Army Tank-Automotive Command (TACOM) through the Army Weapons Command (WECOM).

2.3. TACOM Phase.

2.3.1. At the time TACOM assumed responsibility, the run-indefinite M113 carrier's had acquired an average of 3610 miles.

(NOTE: In November 1964, TACOM was requested to recommend an interim maintenance policy based on the data collected and analyzed up to that time. A 4000 mile combat vehicle overhaul policy was forwarded in January 1965. This policy was published on 6 Aug 65.)

2.3.2. In September 1965, DA curtailed further run-indefinite testing in Europe after USAREUR reported difficulties in maintaining the project. Then on 1 January 1966, DA directed the 50 M113 carriers be returned to the United States for further testing.

2.3.3. The vehicles were turned into the Germershiem Depot in Germany in March 1966. Thirteen months later (April 1967), the vehicles arrived in the United States.

2.3.4. Upon arrival in CONUS, the 50 vehicles were distributed to 4 sites for further testing to accumulate the targeted 10,000 miles.

2.3.5. Two were shipped to FMC Corporation, San Jose, California. These vehicles were run for the entire 10,000 miles, torn down and evaluated. A complete report, (Logistical Evaluation Study of APC's - Technical Report, Project Authorization 2880-40), including recommended product improvements, was completed in June 1968 and was distributed at that time.

2.3.6. An additional 2 vehicles were sent to the US Army Armor and Engineer Board at Fort Knox, Kentucky, while 3 went to the Aberdeen Proving Ground in Maryland, for test by the US Army Test and Evaluation Command (TECOM). TECOM requested that the tests on these 5 vehicles be cancelled because of their deteriorated condition.

2.3.7. The remaining 43 M113's were sent to Fort Carson, Colorado, for continued testing by field troops. The Continental Army Command (CONARC) immediately objected to the issuance of the vehicles in an unserviceable condition. Consequently, the vehicles were diverted to the Pueblo Army Depot, Colorado, for repairs to upgrade them to meet field maintenance service standards.

2.3.8. The number of vehicles slated for Fort Carson was reduced to 32 to conform to unit level Table of Equipment authorization, 15 each to two companies and two vehicles held in a float status.

2.3.9. The vehicles were repaired to field maintenance standards at Pueblo Army Depot during the summer of 1967 and transferred to Fort Carson around the first of the year 1968. The vehicles were run until May 1970 when the test was terminated at the request of the Fifth US Army because of lack of operating funds, personnel to collect and report maintenance data, difficulty in obtaining repair parts when CONARC was in process of converting from gasoline vehicles to the newer diesel engine models, and because of SEA priority. The Department of Army approved the termination based on low vehicle mileage accumulation, as low as 49 miles for the entire fleet in one month, and the ensuing lengthy period to operate the vehicles to 10,000 miles.

2.3.10. A sample copy of the Fort Carson Evaluation Test Report, FC Form 1238, is shown on Figure 1. This report along with the standard reporting on Equipment Serviceability Criteria were the basic documents used to compile data during the test.

2.3.11. The repair parts replacement section was double-checked against a special run of TAMMS data for the vehicles in the test fleet. In some cases, the on-site report did not agree with the TAMMS data.

APPENDIX II

METALLURGICAL REPORT

AMSTA-RKA (21 Apr 75)
SUBJECT: Authorization of Charges for Metallurgical Services on Testing of Steel Shrouded Roadwheels

TO	Act C, Armor & Comp Div (AMSTA-RK) ATTN: Mr. Cameron	FROM	Act C, Armor & Mat Appl & Tech Func (AMSTA-RKA)	DATE 9 Jun 75	CMT 2 Mr. Binder/is/32065

1. Metallurgical examination of submitted steel shrouded roadwheels and broken steel rims has uncovered evidence which shows that the rims were not fabricated as required. The examination also showed that the condition of non-conformance was related to the failure of the rims.

2. Engineering Drawing No. 3CP102, Revision A, dtd 13 July 1973, depicts the rim as a continuous joint-free, ring-like structure having a 24-inch O.D., and a 21.63-inch I.D., with a 2.88-inch flange. The material requirement is for a SAE 1040 steel or equivalent. In our investigation, however, we observed that, although the rims met the geometrical (ring-like) requirements, it appeared to be formed from two different materials. Evidence of this was first discovered during visual examination of a Nital etched section from a broken rim. At that time, a distinct light etching band was observed in the fracture area. Further investigation showed that such a band was also present in all the remaining rims and steel shrouded roadwheels (see Figures 1, 2 and 3).

3. Since the visual appearance of the band area suggests that these rims were possibly formed by welding together two different materials, all steel shrouded roadwheels were dye-penetrant inspected and broken rims were sectioned for metallurgical and chemical examination to validate this assumption. We were unable, however, to uncover any indication of a weld joint by dye-penetrant examination, but did find a crack in the band area of one of the roadwheels (see Figure 3). Metallographic examination of parallel and cross sections through the fracture of the rims (band area), however, showed that the material structure in the band area differed from that outside the band area. Figures 4 and 5 show this condition. Figure 4 is a photomicrograph taken from a section parallel to the surface of the band area and shows a microstructure of ferrite and pearlite. The large percentage of ferrite (white area) in comparison to the amount of pearlite (dark area) presence is indicative of a low carbon steel. A photomicrograph of a cross

AMSTA-RKA (21 Apr 75)
SUBJECT: Authorization of Charges for Metallurgical Services on Testing of Steel Shrouded Roadwheels

section through the fracture shown in Figure 5 also reveals this condition. Note that there is more ferrite present in the top half of photomicrograph and that the pearlite becomes increasingly greater near the bottom. The top portion of the photomicrograph represents the light etching portion of the band area and the bottom portion that of the area outside the band area. Note also that there is a change in grain size from top and bottom. This latter condition suggests the application of heat, possibly that produced during welding. We speculate, however, that the rim may have first been formed into a flat ring with a welded splice, and that this weldment was annealed, then spun to the final rim configuration, machined or welded annealed and then machined. The heat treat process, we believe, would account for the lack of a definite weld joint in the sections examined.

4. Chemical check made in the band area and adjacent to it, and at a location away from the band, confirmed our metallographic observations that two different materials had been utilized in construction of the rim (see Tables 1 and 2). The results show that the ring was constructed of SAE 1045 steel, an acceptable equivalent for SAE 1040, and the band material was a non-standard, low carbon (0.09% carbon) steel.

5. In addition to the aforementioned examination, we also performed hardness measurements on sections through the broken rims. Rockwell "B" hardness surveys showed that the hardness ranged from RHB 86.8 to 90.8 in one section and RHB 87-86.9 in another section. The higher hardness values which were measured before the fracture are attributed to cold working of the steel.

6. On the basis of tests performed and observations made, we have concluded that the method of fabrication was a contributing factor to the failure of the steel shrouded roadwheels.

7 Incl
as

EDWARD MACKIEWICZ
Act C, Armor, Mat Appl & Tech Func

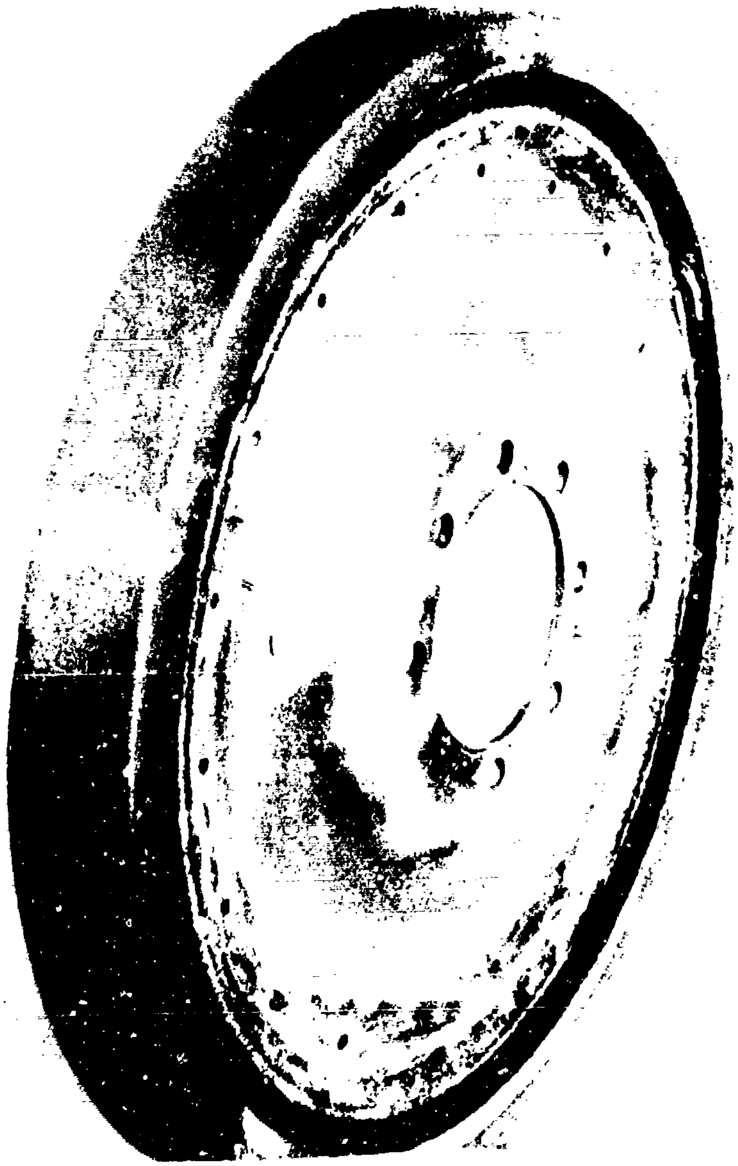


FIGURE 1

STEEL SHROUDED ROADWHEEL AND LIGHT ETCH BAND
(2% NITAL ETCH)

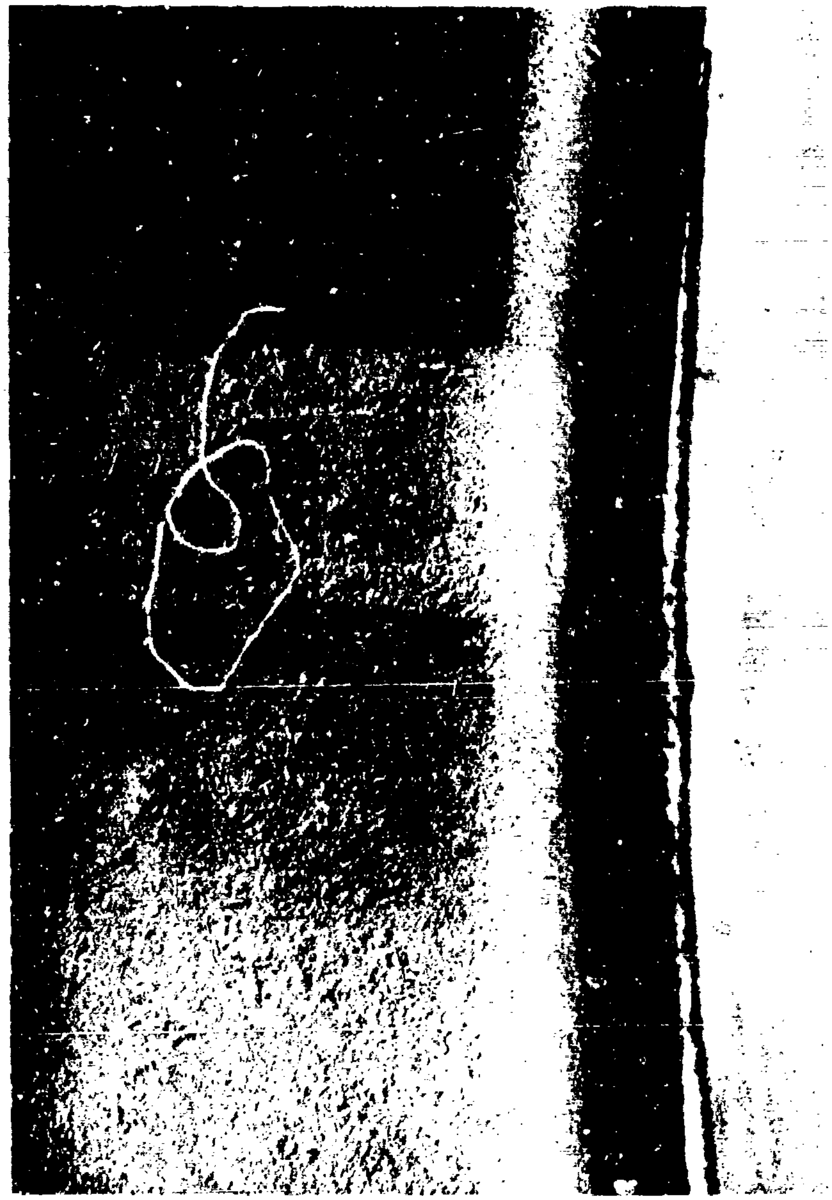


FIGURE 2

LIGHT ETCH BAND (TOP VIEW)

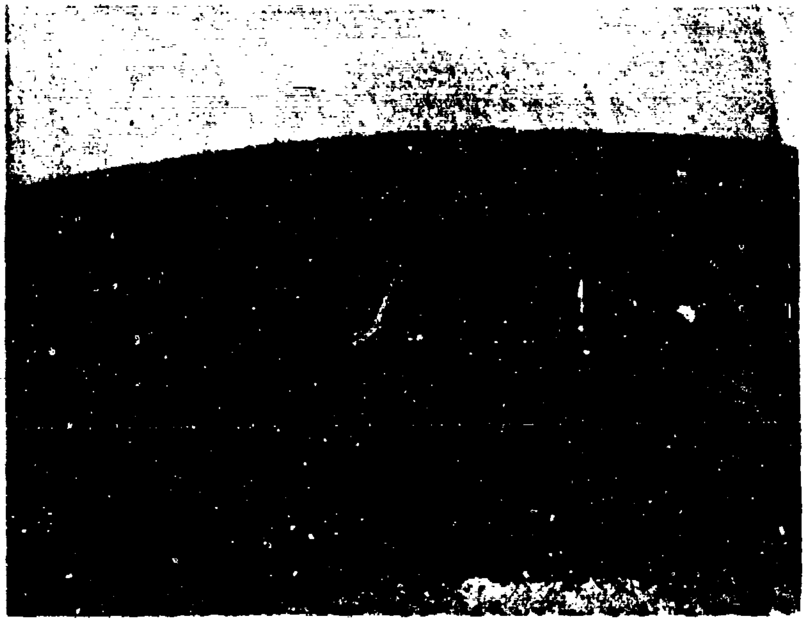


FIGURE 3

CRACK IN LIGHT ETCH BAND
(SIDE VIEW, ARROW POINTS TO CRACK)

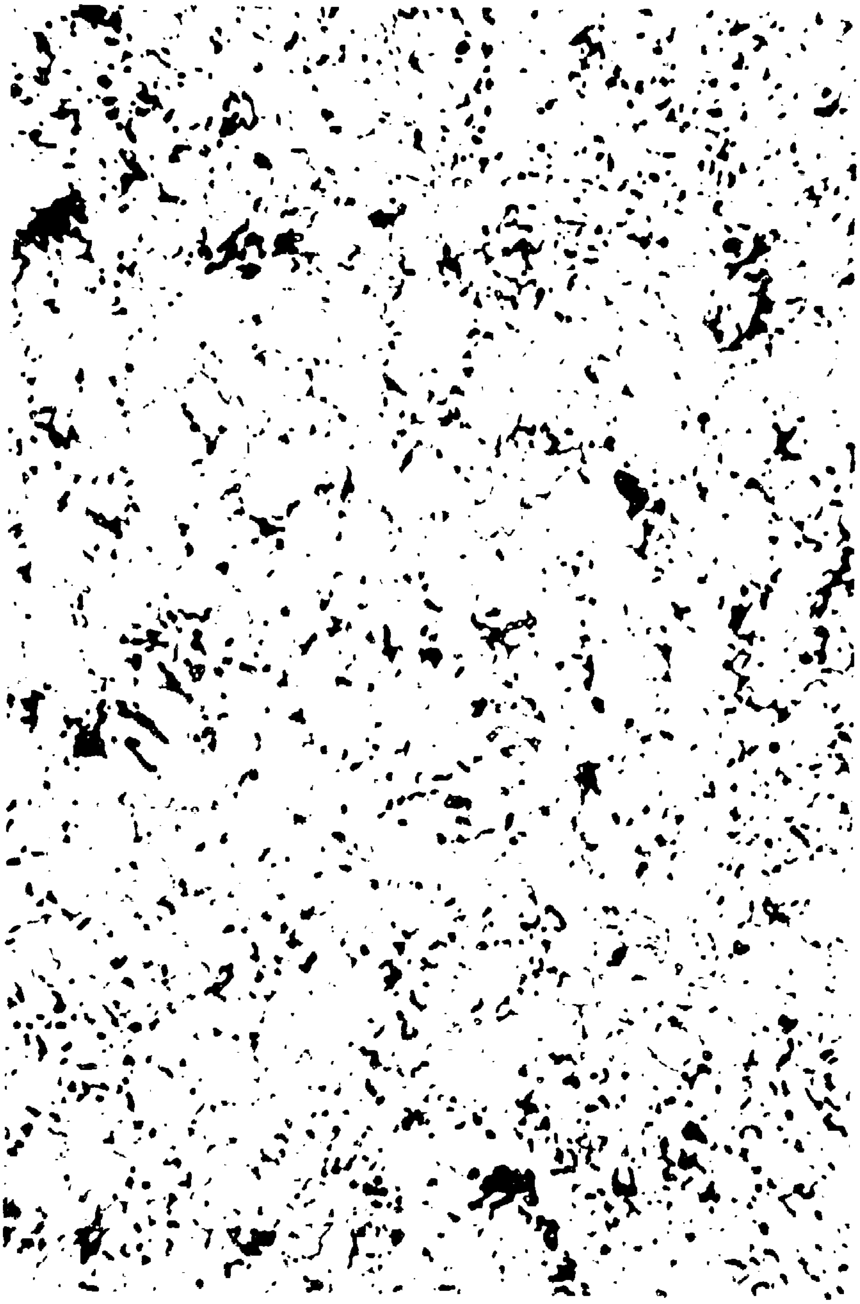


FIGURE 4

LIGHT ETCH BAND MICROSTRUCTURE
(2% NITAL ETCH, 200X)

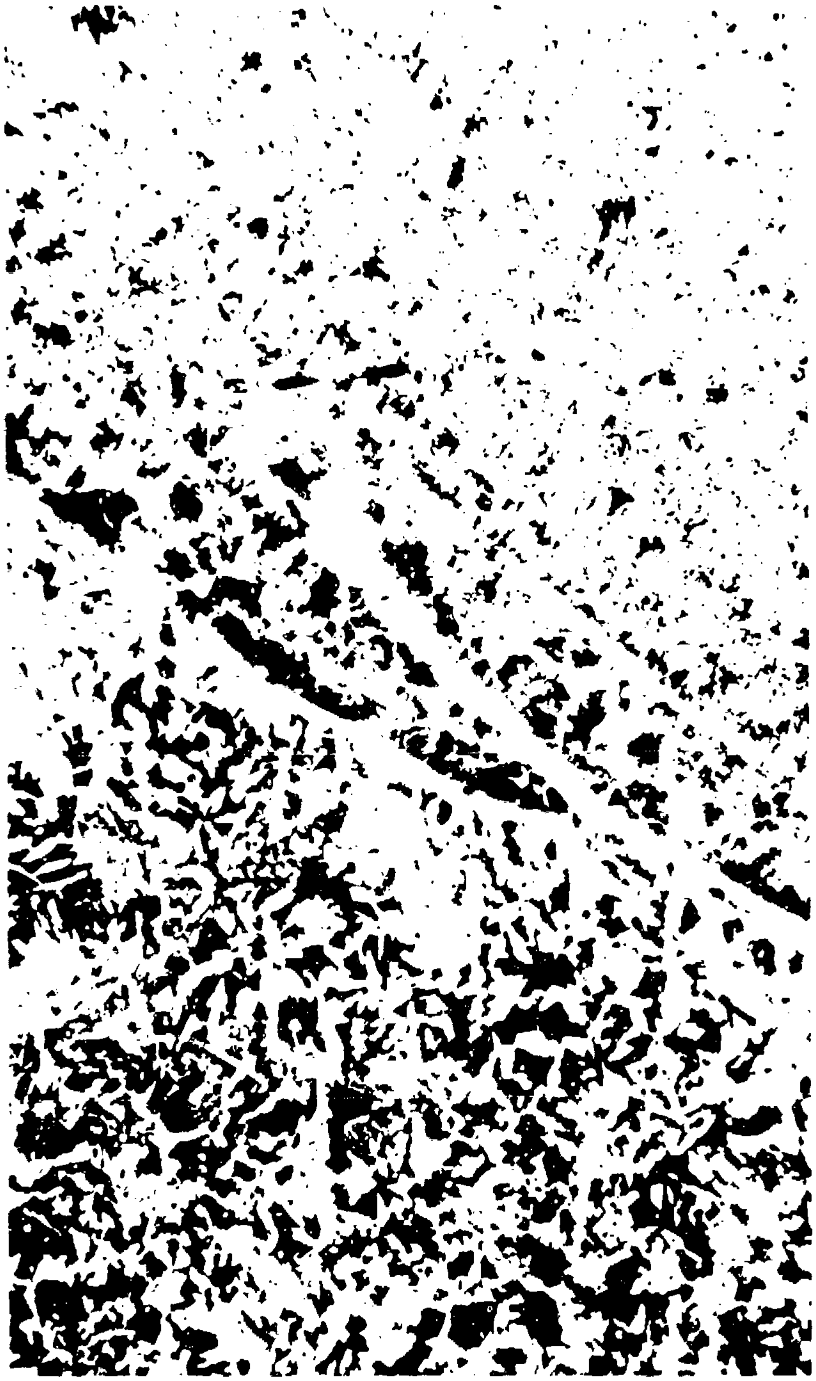


FIGURE 5

LIGHT ETCH BAND - BASE METAL TRANSITION
(2% NITAL ETCH, 110X)

TABLE 1

CHEMICAL ANALYSIS

Chemical and Spectrographic Units

1. Samples: A - band area; B - adjacent to band area

2. Results:

ELEMENT	SAMPLE A	SAMPLE B
Carbon	0.06	0.42
Sulfur	0.012	0.007
Phosphorous	0.02	0.004
Manganese	1.44	0.63
Silicon	0.62	0.17
Chromium	0.03	0.06
Nickel	0.02	0.01
Vanadium	Trace	0.00
Copper	0.04	0.02
Aluminum	0.02	0.02
Molybdenum	0.00	0.00
Tungsten	0.00	0.00

S. B. Catalano
SPECTROGRAPHER

TABLE 2

CHEMICAL ANALYSIS

Chemical and Spectrographic Units

1. Sample: Steel rim, P/N 3GP1012, six inches from band area

2. Results:

ELEMENT	
Carbon	0.50
Sulfur	0.014
Phosphorous	0.008
Manganese	0.63
Silicon	0.17
Chromium	0.05
Nickel	0.02
Vanadium	Trace
Copper	0.03
Aluminum	0.03
Molybdenum	0.00
Tungsten	0.00

S. D. Catalano

SPECTROGRAPHER

APPENDIX III
METHOD OF MANUFACTURE

AMSTA-RKT 3 Jun 75

MEMORANDUM FOR THE RECORD

SUBJECT: Steel Shrouded Roadwheels

1. of Company phoned me on 2 Jun 75 with a report he had finally received from the company that had furnished them the steel shrouds regarding method of manufacture.

2. The source company was Company (telephone number:) and the person contacted was Mr. . They produced the shrouds as follows:

A thick walled tube (of the order of 24-1/2" O.D. x 21-1/4 I.D.) was produced by rolling 1045 steel plate, welding with 100% penetration by a certified welder, using submerged arc welding and low hydrogen rod, X-raying the weld, stress relieving, then cutting off rings which were subsequently machined to produce the finished steel shrouds.

3. It should be noted that we had originally spoken to about rolling these shrouds from thin plate rings to avoid any welding - though we realized the rolling might be difficult and might require heating because of work hardening with so much cold working.

John Cameron
JOHN CAMERON
Project Engineer

CF: Mr. [illegible]. Binder
(AMSTA-RKMC)