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FAILURE MODE OF THE WEFTLESS BEAD AND EVALUATION OF IMPROVED CONTINUOUS SINGLE WIRE BASED BEAD

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ABSTRACT OF THESIS

**FAILURE MODE OF THE WEFTLESS BEAD AND EVALUATION OF
IMPROVED CONTINUOUS SINGLE WIRE BASED BEAD**

Weftless Bead design has long been in existence and still used in many passenger car, bus, truck and agriculture tractors. The ideal bead design is a high strength flexible cable with minimal cross section   and covered by rubberized nylon, rayon or steel wire side wall. The basic tire bead designs are weftless bead with rubberized ribbon of parallel wires of multiple wound layers and a continuous wire wound in sufficient number of loops to give the required strength. Weftless bead failures generally occur within about 5cm from the end of the overlapping parallel wire ribbon. The cause for this failure is generally attributed to the mounting process in which the diameter of the tire bead is changed during the mounting process in the well of the rim. A finite element model of the tire bead was developed and under the known stresses of the mounting and final use conditions. The Weftless bead generally consists of five steel wires in parallel in a continuous rubber tape or ribbons, which loosely secures the wires in a soft insulating rubber. The ribbon is wound into a hoop with four courses resulting in a grommet composed of a stack of wires. This ribbon with ten cut ends forming a splice, with five at the inner cut edge and five at the outer cut edge. A continuous bead formed from a single wire does not have this failure prone splice region. Field data and the finite element calculations show the failure point of the weftless bead is almost always at the under lap or at the starting point of the weftless bead. Continuous wire bead have significant advantages in safety over the Weftless bead still used in tires.

KEYWORDS: Tire Bead, Tire Failure, Weftless bead, Continuous Single Wire Bead.

Arun Kumar Doradla

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THESIS

Arun Kumar Doradla

The Graduate School

University of Kentucky

2005

FAILURE MODE OF THE WEFTLESS BEAD AND EVALUATION OF IMPROVED
CONTINUOUS SINGLE WIRE BASED BEAD

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THESIS

_____

A thesis submitted in partial fulfillment of the

requirements for the degree of Master of Science in Mechanical Engineering

in the College of Engineering at the University of Kentucky

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2005

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DEDICATION

To My Parents

ACKNOWLEDGEMENTS

My first and foremost thanks go to my academic advisor Dr. O.J.Hahn for all the interest and commitment he has been showing in completion of my Thesis. I will always be grateful to him for this, irrespective of whatever heights I may reach in my life. I wish to thank the thesis committee: Dr. Keith Rouch and Dr. Marwan Khraisheh for readily agreed to be on my committee and providing insights. I also would like to thank Dr. Keith Rouch for helping me with ANSYS a number of times.

It is needless to mention that my family, friends and relatives have been constant sources of strength, courage, and encouragement.

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Chapter I

1.1. PURPOSE OF RESEARCH

The modern pneumatic tire is a complex load carrying structure obtaining its support namely air pressure, a tire is a very flexible structure with countless problems. Many of these problems arose from the necessity of combining several highly dissimilar materials into a finished product that must function as a unit. The pneumatic tire is an outstanding example of attempts to get a lot of different things working together harmoniously. First, the tire casing itself is complex with several dissimilar materials such as rubber, textile materials, compounding ingredients and steel plus a relatively small amounts of other materials. Secondly, tire is a unique element that must work harmoniously with the rim and other wheel parts.
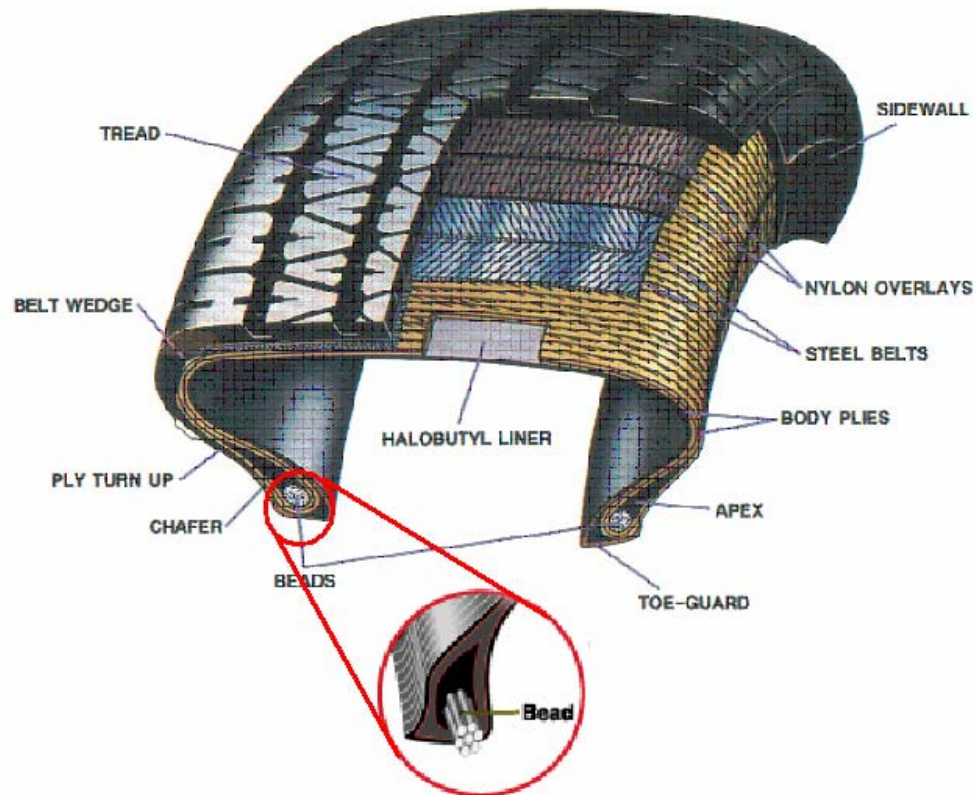
Figure 1-1 Weftless Cross-Section

Structural regions and components of a tire are shown in Fig: 1-1, the terminology shown is generally accepted, although it may differ some what among manufacturers

The carcass piles, beads, belts and thread are considered primary components because they are responsible for the fundamental tire characteristics, geometric shape and stress capacity. The secondary components such as chafers, flipper and breaker reinforce or protect the primary components from high stress concentrations by distributing forces.

Tires fail under static and dynamic conditions for a number of reasons which include design, material, manufacturing defects, lack of quality control, inspection, handling, mounting procedures, maintenance, use conditions, rethreading and use beyond safety limits.

The bead is the inner edge of the tire that contacts the wheel flange and presses against the bead seat. The bead seals against air loss in tubeless tires and grips the wheel rim for transmitting various loads such as steering, traction and braking. Bead failure can cause loss of air pressure in the tire as well as detachment of the tire from the rim. Bead failure may cause loss of vehicle control and, possibly, an accident.

Weftless bead was designed in about 1930 and employs a wire of 0.037"diameter. The proneness to and the frequency of the tire bead grommet failure with bead grommets of the Weftless design during tire bead seating operations has been understood in the tire manufacturing industry for since 1955, as also has the mechanism and design feature responsible for it and the design means of preventing it. Weftless bead generally imbeds four or five steel piano wires in parallel in a continuous rubber tape or ribbon, wound into a hoop, with four or five strands. This bead bundle or grommet has ten cut wire ends: five at the inside cut edge, or at the beginning of the bead wrap, and five on the outside cut edge, at the end of the bead wrap. Assuming the inside cut edge or starting of the bead bundle, to be positioned at the twelve o'clock position, a clockwise wrap of the bead ribbon would result in the outside cut edge being found at the one o'clock position. This area of overlap between the twelve and one o'clock position is called the bead splice.

Virtually every tire bead failure occurs in the location of bead splice at the inside cut edge of the five wires that start the bead. During a tire accident when the wires in the grommet become unstabilized and distorted, the combined strength of the bead grommet

is lost. This distortion can be prevented when the bead is being seated onto the rim of a drop center wheel. The explanation for this fact is that a splice, by definition, is always a weakest point and prone to separation and distortion.

In the process of bead failure, the bead bundle will separate into a configuration where not all the wires in the bead bundle are carrying an equal load. The wires forming the grommet can then become separated and only one wire can end up carrying the full inflation load of the pressurized tire. If by chance the unstabilized location happens to be in the area of the splice at the inside cut edge of the ribbon where the bead bundle begins, the tensile strength of the wire carrying the full load of the inflating air is exceeded and it fails. At the instant when the first wire breaks, the load is immediately transferred to the next wire which breaks and in rapid succession all of the wires in the bead bundle rupture. But note that a bead will not break unless the beginning of the bead wrap, splice, or area of overlap, is trapped and is the last to seat.

The specific purpose of this investigation is to develop a finite element model of the weftless tire bead and continuous bead in ANSYS and satisfactorily predict the stresses due to mounting and final loading conditions.

1.2. HISTORY OF TIRES

3500 B.C man invented the greatest invention ever seen 'THE WHEEL'. The wheel is one of the greatest inventions due to its wide range of applications include any type of transportation; whether it is people, materials, or equipment being moved. Thousands of years later, the wheel has come long way. The early wheel was a very simple with a solid curved piece of wood. Then leather was eventually added to soften the ride, as time progressed it became solid rubber which led to today's tire. Rubber was not useful as it is today. Early rubber did not hold shape; it would be sticky in hot weather and become inflexible in the cold. In 1839 Charles Goodyear was credited with the discovery of the vulcanization process. Vulcanization is the process of heating rubber with sulfur. This transforms sticky raw rubber to firm pliable material which makes rubber a perfect material for tires.

Soon after the discovery of vulcanization process solid rubber tires were made and these tires were strong, absorbed shocks and resisted cuts and abrasions. These tires were very heavy and did not provide smooth ride. Today these type of tires are still seen in forklifts, Cranes etc. Robert. W. Thomson, a Scottish engineer, first patented the pneumatic tire, which uses rubber and enclosed air to reduce vibration and traction. In 1888 John Boyd Dunlop of Ireland became the second inventor of the pneumatic tire and caught the public attention for his invention and was extremely popular in cycle tire. In 1895, Michelin is the first person to use the pneumatic tire on automobile, however not successful for his act. For the next fifty years from the early nineteenth century vehicle tires were made up of inner tube that contained compressed air and an outer casing, this outer casing protected the inner tube and the tire with traction. Layers called ply's, made of rubberized fabric cords that were embedded in the rubber, reinforced the casing. The tires with ply's running diagonally from one bead to other are called bias-ply tires. and this are still seen today in certain type of off-side tractors. In 1948 radial tires were first appeared in Europe with the ply cords made of rayon, nylon and polyester radiated at a 90 degree angle from the bead, and the casing is strengthened by a belt of steel fabric that runs around the circumference of the tire. Radial tires are seen today in almost every passenger car and trucks with advantages include longer thread life, better steering and less rolling resistance, which increases gas mileage. On the other hand, radials have a harder riding quality, and are about twice as expensive to make.

1.3. DESCRIPTION OF THE TIRE BEAD AND ITS COMPONENTS

According to NHSTA bead is defined as follows: "Bead" is defined to include all of the materials below the sidewalls in the rim contact area, including:

Bead rubber components;

Bead bundle and rubber coating if present;

The body ply and its turn-up including the rubber coating;

Rubber, fabric, or metallic bead reinforcing materials; and

The inner-liner rubber under the bead area.

Radial tire has more flexible side wall, causing more movement in the bead area

1.4. TIRE BEAD FAILURE

Tire beads (Ref-3) in new tires can be defective and cause premature tire failure. Some of the factors contributing to tire bead failure is given below.

1.4.1 Bead Stresses: Uniform stresses are created by bead resisting a constant pull, created by the inflation pressure, superimposed on these uniform stresses are a number of tensions by varying centrifugal forces, road irregularities, vehicle braking, cornering and travel waves developing in a tire

1.4.2 Improper Mounting Procedures: Damage of tire beads can occur during mounting and changing procedures. This damage can be of a direct type resulting in bead kinking, distortion and other types of damage. Damage to the wire in the bead grommet can lead to eventual tire failure or failure during mounting. One of the main reason for bead failure is the carelessness of a service attendant or the inexperience of the tire service man. The use of heavy crowbars, hammers, improper use of tire irons or machines to force beads over rim flanges, can cause bead damage.

1.4.3 Bead Manufacturing: Improper bead diameters can find their way into a tire due to mix up in bead grommet sizes during manufacturing. A bead grommet that is too small can be broken during tire curing stage. Materials displacement due to compression of the fabric and rubber underneath can occur, resulting in the bead toe becoming thinned and extended. When bead grommet is too large, the forces used during tire manufacture can cause the bead to become kinked or wavy and separation between the turns of the wire.

1.4.4 Bead Vibration: Bead vibration creates fatigue producing stresses. The main reason for producing bead vibration is poor adhesion between the bead wire and the surrounding rubber. This vibration results in a separation between the rubber and metal resulting in the admittance of moisture and other corroding agents. The wire then

becomes subjected to fatiguing stresses and corrosion. Good adhesion between wire and rubber dampens bead vibration.

1.4.5 Wire Finishes: The finishes used on bead wires developed over years are

the common bright finish created by the use of lime or substitute material before the final drawing operation results in poor adhesion to rubber

Electroplating the bead wire by a bath of molten metal results in poor corrosion resistance and rubber adhesion

Galvanizing the bead wire with a molten bath of zinc provides protection against corrosion, but poor in rubber adhesion

Bronze and brass plating results in good adhesion but does not provide high resistance to corrosion

Tinning of wire does not provide good rubber adhesion or corrosion resistance

Tin and cooper coating by placing the bead wire in acid solution of tin and cooper results in fair adhesion to rubber

The Avery process No.1 (AP-1) finish by combination of a coat of zinc followed by copper electroplating over, to create rubber adhesion qualities is considered as best by bead specialists.

1.4.6 Handling And Storage: Improper handling and storage methods of bead wire initiates a failure in bead wire.

1.4.7 Corrosion: Corrosion of bead is controlled in part by the wire finish. Moisture is one of the chief enemies of the bead wire.

2. TIRE BEAD

Chapter-II

2.1. INTRODUCTION

Bead is a component of tire incorporates during the construction of the tire and secures a tire to the wheel. The tire bead is a structure composed of high strength tensile steel wire formed into a hoop, functions as an anchor for the plies and holds the tire assembly onto the rim of the wheel. The tire bead is the inner edge of the tire that contacts the wheel flange and presses against the bead seat. The bead seals against air loss in tubeless tires and grips the wheel rim for transmitting various loads such as steering, traction and braking. Tire bead failure can cause loss of air pressure in the tire as well as detachment of the tire from the rim. Bead failure or a tire bead explosion may cause loss of vehicle control, injury and even death.

2.2. DIFFERENT TYPES OF TIRE BEAD REINFORCEMENTS

Over the period (Ref-1) of more than a century different varieties of bead materials and constructions have been tried and sometimes used. But today only one reinforced material is employed in several different ways for bead reinforcement they are

2.2.1 Weftless Bead: Several parallel steel wires coated with rubber compound and wound into the form of a stranded ring. The compound holds the strands together while the bead is being manufactured.
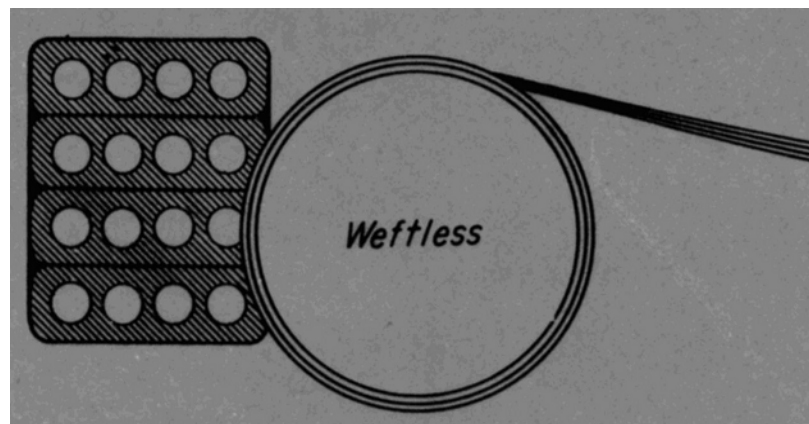
Figure 2-1 Weftless Bead
Courtesy: The story of Tires and Tire beads

2.2.2 Tape Bead: Three or thirteen parallel straight wires held in the form of a flat tape by a fine filler wire woven back and forth in zigzag pattern, coated with rubber, and wound on a form to produce a stranded ring. The filler wire holds the other wire strands together during processing.
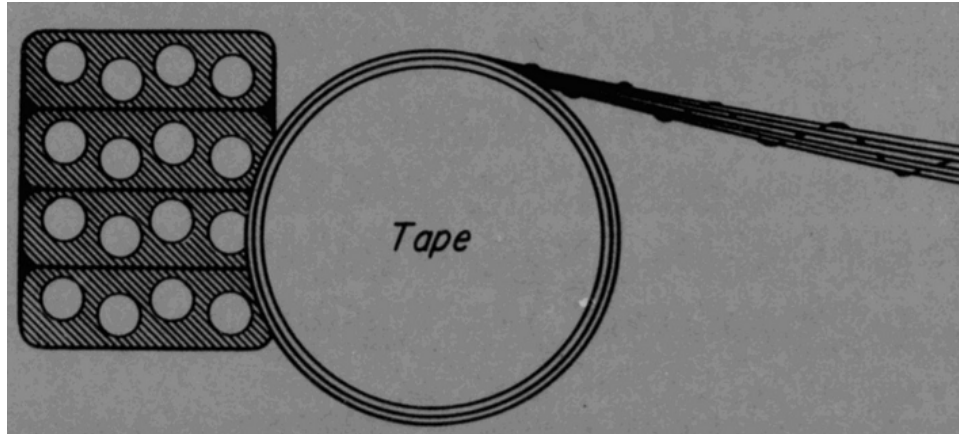
Figure 2-2 Tape Bead
Courtesy: The story of Tires and Tire beads

2.2.3 Braid Bead: thirteen to twenty-one strands of steel wire braided together to form a flat band and then covered with rubber and wound the required number of times around a form, to produce a ring or hoop.
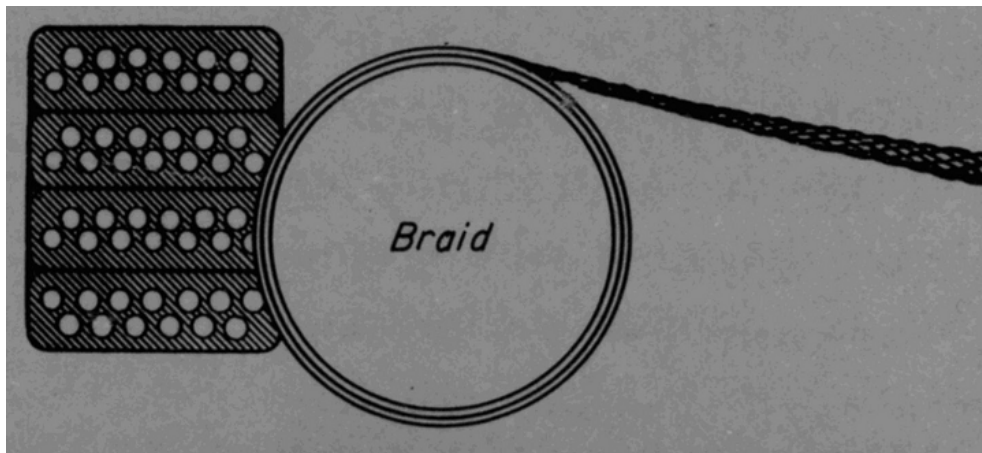
Figure 2-3 Braid Bead
Courtesy: The story of Tires and Tire beads

2.2.4 Cable Bead: One or two strands of the steel wires are tightly intertwined around a flexible heavy cord called core forming a cable bead.
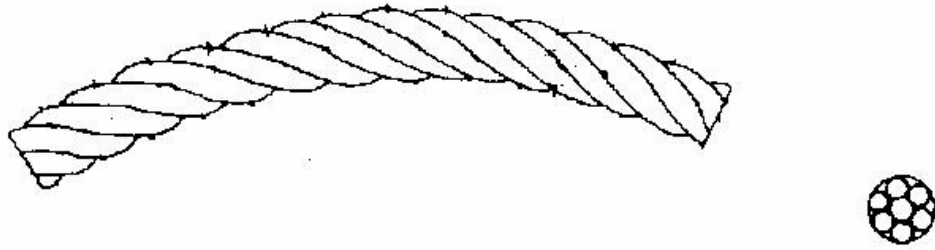
Figure 2-4 Cable Bead

2.2.5 Single Bead: A single rubber covered strand of wire wound around continuously to from a ring-shaped bead grommet also called continuous single wire bead.
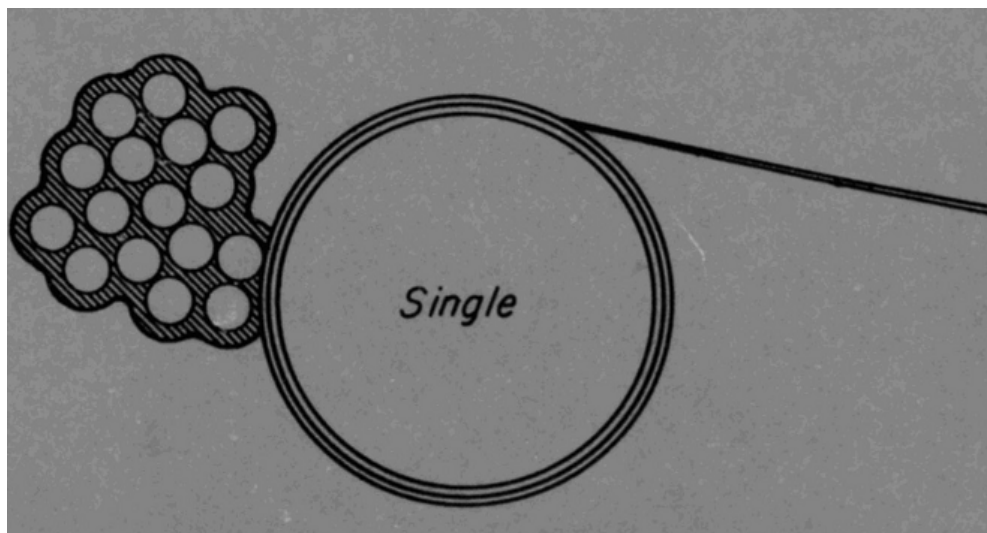
Figure 2-5 Single Bead
Courtesy: The story of Tires and Tire beads

2.3. FAILURE MODES:

Explosions of passenger tires occur during mounting procedures and such explosions are often of a magnitude to cause injury and death to service personnel as well as property damage. Causes of such explosions are improper bead design and positioning, substitution of 6 ply bead for a 4 ply tire, smaller diameter at bead area for the rim being used, a bead kinked during tire and bead manufacture, etc. In the case of a used tire, a bead can be weakened by prior improper mounting procedures causing a fracture of the bead bundle cover allowing entrance of moisture resulting in a chemical corrosive attack

on the bead metal, thus weakening the bead. Prior mounting procedures and subsequent work can cause bead kinking that initiates failure.

Tire beads are the foundation of a tire whose chief function is to hold the tire on the rim. The inflation pressure is constantly trying to force the beads off the rim and without the rim flange the heel of the bead would be forced off the rim ledge. Operational stresses intermittently strive to accomplish the same thing as the tire bead is the connecting link through which the vehicle load is transferred from tire to the rim.

Present day passenger cars use drop center rims. These rims were suggested in the late 1800's and inventors called them as "rims with depressed centers". (Ref:4). The depressed part of the rim served as a space into which one tire bead was forced so the tire, in a diametrically opposite point could be pulled over the rim flange. Removing the tire was accomplished by a "button-holing" technique. When this rim was used in passenger car tires number of problems arose. The greater lateral stresses associated with vehicle wheel behavior caused the tire beads to be forced into the rim well when the vehicle was in motion. Several modifications of this rim and tire developments revised the use of the drop center rim in the 1920's after it had been abandoned shortly after it was first introduced in the early 1900's. Tire beads were stabilized to prevent "rocking" that caused inner tube chafing. This was accomplished a tighter fitting of the tire to the rim by better tire bead design. By 1929 this type rim was adopted by American passenger car manufacturers.

The technological advancement in tire and bead design reduced the problems of tire beads being forced into the rim-well when a car was in motion. Further modifications in the form of an inclined bead seat rim were designed to replace flat rims. Drop-center rims were, at this time, made with cylindrical bead seats. The use of low inflation pressures of balloon tires caused problems in securely seating beads on the cylindrical seats. Lower inflation pressures would not hold the beads tight enough against the rim flanges. This problem was overcome with the inclined bead seat design of both the tire bead and rim.

The inclined bead seat design in rim provided an incline upward over which the bead traveled to finally seat against rim flange. This design provided a

wedging action for a tighter fit. By this time the drop-center rim became an integral part of the wheel and demountable rims were no longer used.

A further rim design development included the rolling of a "hump" around the rim between each bead and rim wheel. This design was to prevent any tendency the beads might have to slip into the rim well in event of a tire failure and allowed more vehicle control through better stability of a defined tire while bringing a car to a stop. This development also brought about problems in mounting tires. If these developments were not understood by service-men, resulted in exploding tires in greater numbers than when a rim without the hump was used.
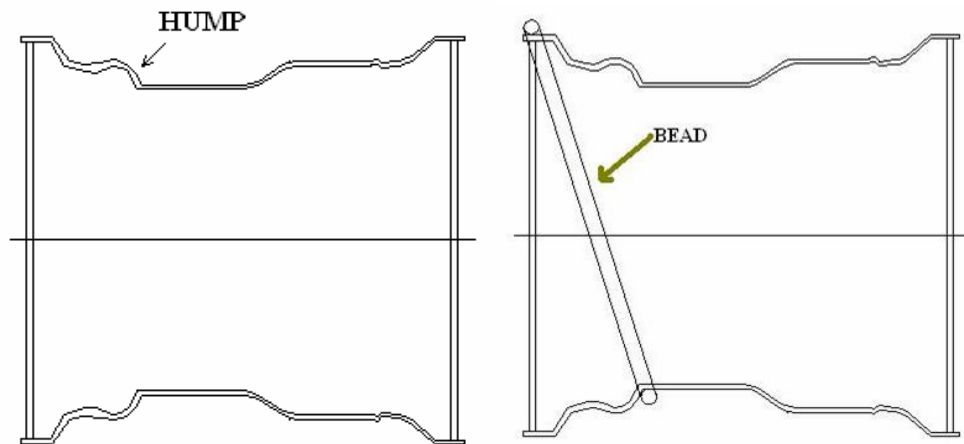
Figure 2-6 Drop Center Rim

Each modification in rims or tires has usually brought service and failure troubles when such modifications are initially introduced. The problems are slowly designed out by investigations of the troubles. The basic engineering principle is that any modification of a section of the design usually requires a further modification in order to achieve an acceptable working system. This is well proven in the field of tires and rims and will probably continue.

The inconsistency of diameters of tires at the bead areas when under compression can account for a bead failure during mounting procedures. This problem is aggravated by the use of "hump" type bead seat rim design. Another factor that can cause a tire explosion is a "kinked bead" when the tire is manufactured, and other conditions.

Beating the tire bead with a hammer is only a slight force when compared with 40 pounds per square inch of air in a 1200 square inch surface of tire acting on a "hung-up" bead. The total force is in the order of 24 tons, a great deal of which is acting on the small section of the bead not seated. Even the diameter difference of bead bundle makes the tire bead difficult to seat. Exact tolerances are not possible among all makes and brands of tires. Generally the bead fracture was of a classical cup and cone type usually associated with tension beyond the strength of the bead.

The number of variables that are present in mounting a number of tires makes it almost impossible to predict at what pressures and at what point failure will occur. The hoop-tensile strength of beads is not uniform which also introduces a variable that cannot be predicted. The tensile strength of beads also varies. The attitude of the tire at the time of inflation is another factor that must be considered.

The manner in which a bead comes over the rim edge is controlled by a number of conditions that exist at the time the bead comes under a certain tension and the angle of the bead to the rim. An almost infinite number of variables can be introduced to cause failure or non-failure of the bead as well as the bead coming over them.

2.4. PREVIOUS RESEARCH

In a United States patent numbered 2822141, titled "Tire Bead Construction" issued to Firestone in 1958, the problem of weftless bead and a design modification to prevent it is described. The patent states:

"It has developed that in tires of the type now in common use that the grommet of wire used becomes ruptured or broken too frequently at or near the end of the wire splice when the tire bead is forced onto the rim bead seat during mounting of the tire. Applicant has discovered that such breaking of the bead wire occurs most frequently when the spliced portion of the bead wire grommet is located in the last portion of the tire bead to be seated on the rim, and they have also noted that when an end of the said wire ribbon was disposed on the radial inner surface of the bead grommet that break started at or adjacent to that point.

It has been noted before the present invention that when the wire grommet broke or ruptured in mounting tires that the rupture frequently occurs at the ends of the ribbon that was disposed on the radial inner surface of the grommet. Whatever the explanation may be for breakage or rupture of the grommet at this point it has been observed that this last portion of the tire bead to pass upon its rim seat is drawn radially inwardly forming a short cord of the circle of the tire bead which positions kinks radially outwardly just before it passes on to said bead seat. When the end 21 of ribbon terminated on the radially inner surface of the grommet, as has been a common practice heretofore, and this end fell within the portion of the tire bead that was last to pass upon the rim bead seat breakage frequently resulted, however, if the end of the ribbon on the radial inside of the grommet was not in the last portion of the bead to seat on the rim, no breakage occurred. Since the disposition of the ends of the ribbon cannot be determined when the grommets are built into a tire whether or not they are at the last portion to seat on the tire rim bead is a matter of chance. Applicant discovered that if he moved the beginning end 21 of the ribbon from the inside surface of the grommet that less wire strength required"

2.5. STRESSES ON WIRE IN A TIRE BEAD

In its job of holding tire on a rim the wire bead grommet has to resist a constant pull exerted by the inflation pressure. Therefore the wire is under a uniform stress. In addition when the wheel is turning there are superimposed various other tensions resulting from varying centrifugal forces, road bumps, braking, effects of the travel wave developed in the tire, cornering and so on. Since these superimposed stresses vary resulting in the fatigue of bead wire. Fatigue stresses due to tire revolution work harden the steel wire and may exhibit an increased stiffness and hardness. Then on bead hang-up or a sudden increase in magnitude of this forces results in bending and causes breaking. Probably such fatigue is involved in some of the present day bead wire failure which compared with those of some years back are of rare occurrences.

2.6. WEFTLESS BEAD

2.6.1 Weftless Bead Construction

Weftless bead was designed in about 1930 and employs a wire of 0.037" diameter. Weftless bead tape is made by passing a band of high carbon steel wires through a rubber extruder, which surrounds them with carbon black reinforced rubber components forming a flat tape. Weftless tape extrusion is shown in the figure 2-7 below.

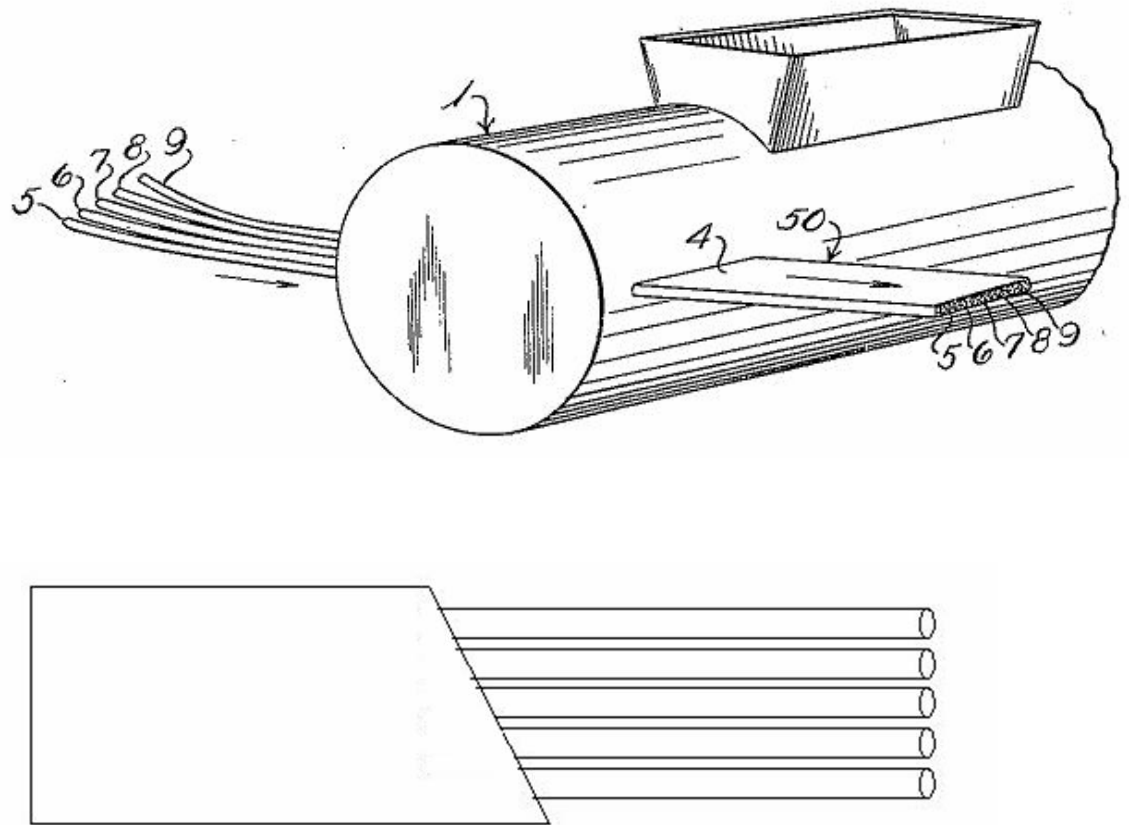**Figure 2-7 Weftless Tape**
Courtesy: Tire Bead Construction

Weftless bead grommet is formed from a weftless tape comprising several parallel wires encapsulated in rubber by winding successive turns of the tape around a cylindrical mandrel of precise design circumference for use in tire. The resulting bead configuration is shown in Fig: 2-8, where the beginning of the bead winding on the radially inner

surface of the grommet is illustrated at A and the end of the bead winding is at B, Where the bead winding extends a couple of inches beyond A. The ends of the wire grommet was simply overlapped without special fastening other than cohesion of the rubber coating, or one or two wire staples are being used to clamp the wires near their ends, the staples forming close fitting bands around the wire bundle. Weftless bead is also known as "Alderfer", "Sterling", "Fillerless", "Multi strand tape", "Webtape" and "Creel bead"
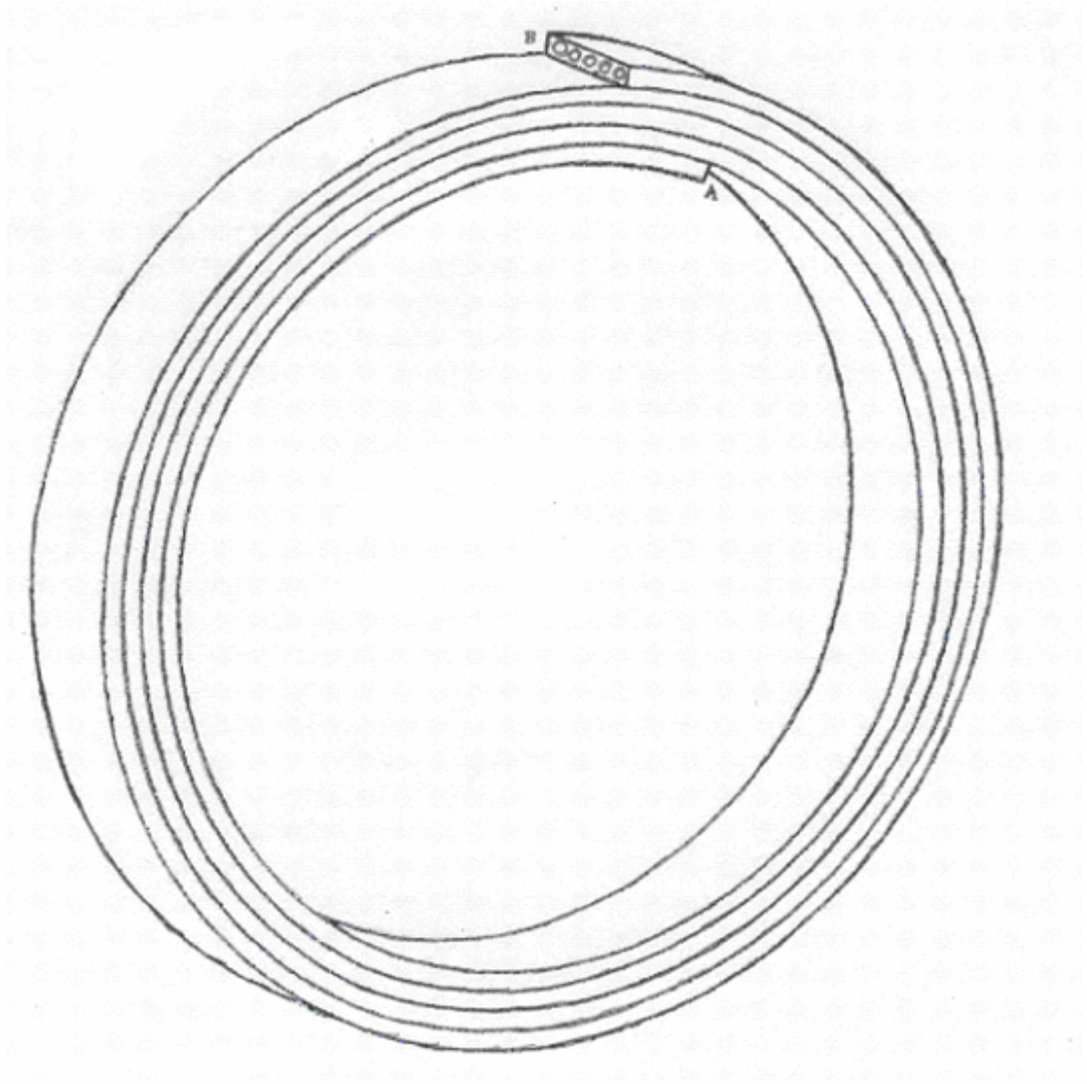

Figure 2-8 Weftless Bead Grommet

The region of the bead grommet between A and B is usually referred by the misnomer "splice" and point 'A' as the inner splice, but is also referred as "underlap" or

starting point of the bead tape winding. The underlap end of the bead grommet is extremely significant because it is precisely at this point A at which bead grommet break when catastrophic failure of the tire bead grommet takes place.

Weftless bead model considered in this study is formed by wounding the weftless tape into hoop with four successive courses. The end result is a grommet composed of a bundle with ten cut wire ends with five at inside cut edge and five at the end of the bead wrap. A cross-cut view of the bead grommet shows a stacking of wires, four high and five wires across, also known as a four by five stack. Assuming the inside cut edge, or starting of the bead bundle, to be positioned at the twelve o'clock position, an anti-clockwise wrap of the bead ribbon would result in the outside cut edge being found at the eleven o'clock position. This area of overlap called bead splice and approximately 30 degrees.

2.6.2 Weftless Bead Failure

The weftless bead (Ref-7) made of 0.037' steel wires individually capable of holding 300 pounds and wound into well constructed grommet can easily 7 tons of air pressure, provided they carry an equal load. When a tire is mounted on a drop center wheel, its beads are forced on by inflationary air pressure within the tire from the drop center well of the wheel onto and against the vertical surfaces of the rim flanges by proceeding outward and sliding up a ramp where the beads are said to "seat" in their final resting position against the rim flange as of Fig: 2-9.
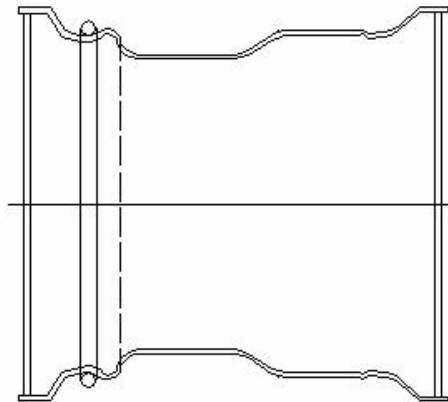

Figure 2-9 Weftless Bead Mounting on Wheel

Distortion in the bead grommet naturally occurs in this process if the area of the bead splice happens to be the last portion of the bead to seat called bead "hang-up" can be seen in Fig:2-10.
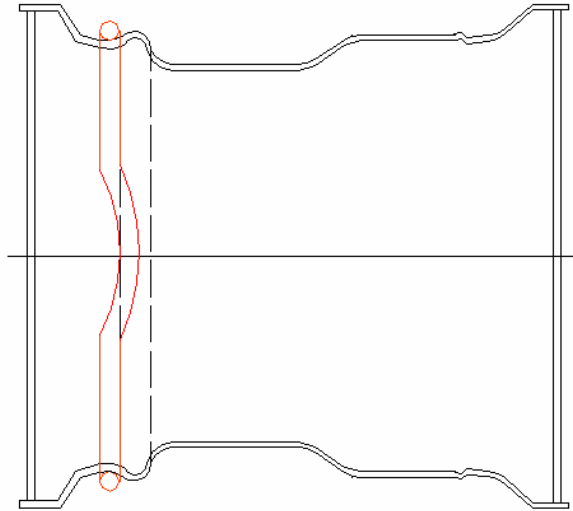

Figure 2-10 Bead Hang-Up

Bead "hang-up" induces stresses (vol-4) in the bead wire and the rim. Drawing on the fig: 2-11 illustrates the creation of stress points due to bead "hang-up". Arrow (E) points to the hump. Location (A) is the point of bead hung, (B) is point bead can break due to hang-up, (C&D) are the points of proper seating.
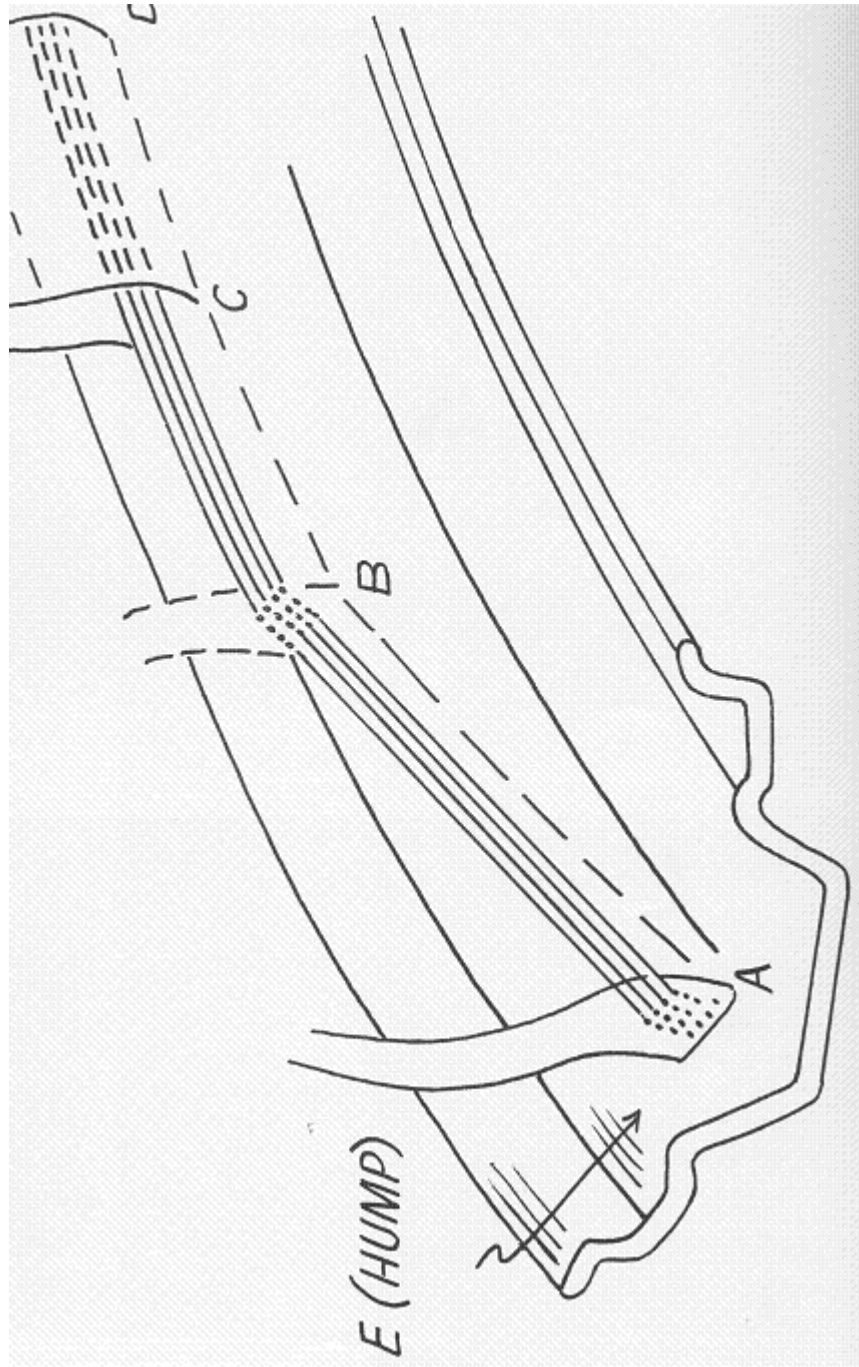
Figure 2-11 Bead Hang-up on Hump
Courtesy: Dynamics of Tire Failure

One explanation for this fact is that a splice, by definition, is always a weakest point and prone to separation and distortion. In the process the grommet of wires, or bead bundle, will separate into a configuration where not all 20 wires in the bead bundle are carrying an equal load. The wires forming the grommet can then become separated and only one wire can end up carrying the full inflation load of the pressurized tire.

If by chance the unstabilised location happens to be in the area of the splice at the inside cut edge of the five wires where the bead bundle begins, the tensile strength of the wire carrying the full load of the inflating air is exceeded and it fails.

At the instant when the first wire breaks, the load is immediately transferred to the next wire which breaks and in rapid succession all of the wires in the bead bundle rupture. But note that a bead will not break *unless the beginning of the bead wrap, splice, or area of overlap*, is trapped and is the last to seat.

Fig:2-12 is an X-Ray (Ref-4) showing the cup and cone tensile fracture of the individual wires of a bead due to "hang-up"

Figure 2-12 X-Ray Shadow Graph Showing Fracture of Individual Bead Wires
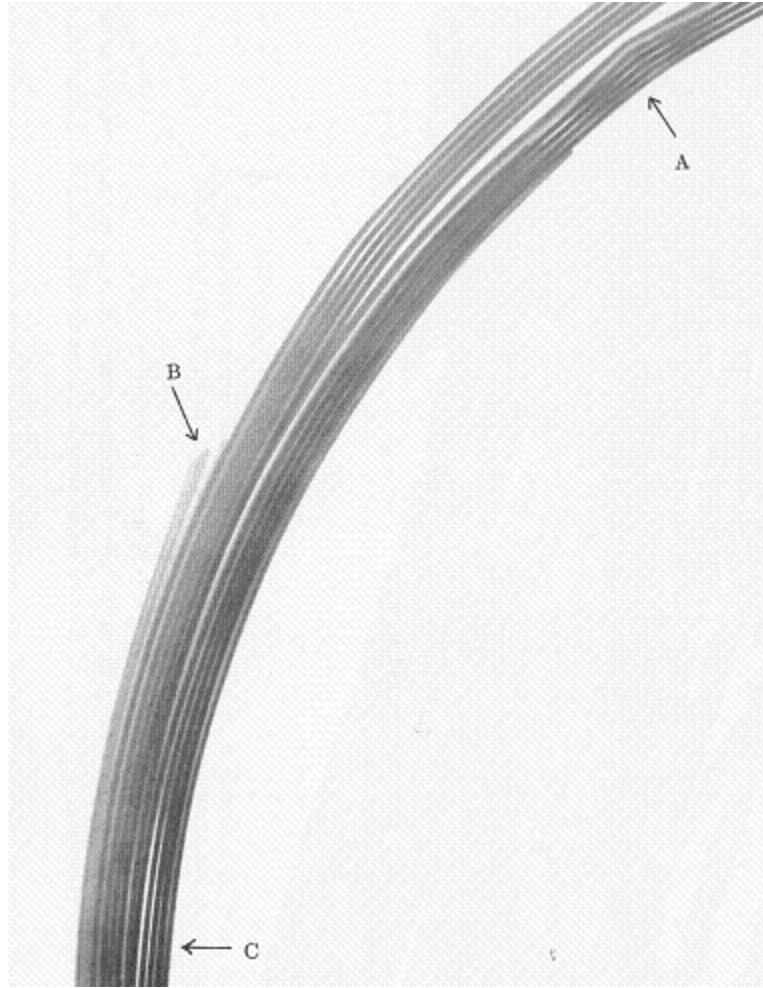Courtesy: Dynamics of Tire Failure

Figure 2-13 X-Ray Shows the Bead Kink, Substandard Bead Tie-Down and Strand Seperation
Courtesy: Dynamics of Tire Failure

The above figure:2-13 is a X-ray with Arrow (A) pointing the bead kink point, (B) pointing substandard bead tie-down and (C) pointing to strand separation

2.7. PREVENTING BEAD FAILURE

The bead almost always breaks at the same spot – the inside cut edge of the splice. Increasing the wire size from the standard .037 inch to .050 would almost double the strength of each wire and adaptation of continuous single wire bead instead of a weftless bead. Another feasible solution is to make the bead one wire, instead of a bundle of smaller wires, so that the well known weak spot is eliminated.

2.8. CONTINUOUS SINGLE WIRE BEAD:

Single wire bead was manufactured by passing a preheated single wire from the reel through an insulating die head of a rubber extruder and then sent through a cooling drum to form a rubber coated wire. In a continuous operation the rubber covered wire was wound in annular form on a driver reel, after the desired number of convolutions had been wound, the wires was cut and the ends forming the bead grommet were overlapped about 1 inch.

The advantages of continuous single wire bead are

Any number of wire convolutions could be obtained in a bead grommet

Single short overlap created better balance with considerably less loss of tensile strength as compared to multiplicity wires

Much stronger bead (burst strength) eliminating the weak hinge point of a weftless bead

Eliminates the need for wrapping the wire start and finish

3. DEVELOPMENT OF BEAD MATHEMATICAL MODEL
Chapter -III

This chapter discusses about the underlying mathematics behind the design of tire beads. The derived equations follow along the lines of the Mathematics Underlying the Design of Pneumatic Tires by Prudy, J.F except with emphasis on radial tires.

A method of assembling the component parts of a tire and vulcanizing it was developed early and almost retained same manufacturing process till date. Unfortunately the materials of which a tire is made permitted a manipulation during the manufacturing process, left the product with inherent stresses that reduced its useful life in service. Increasing severity of service due to newly developed roads and highways gave rise to further stresses.

Analysis of the tire require a equation describing the contour shape and of surface curvature.

The tire by definition is symmetrical about its axis of rotation and symmetrical about the plane in which its greatest circumference lies. The best approach to this problems ahead is by considering a free ring of elementary dimensions cut from the tire in a plane parallel to its plane of symmetry, as MM' of figure 3-1 and then determining the forces required to prevent the ring from altering its size or position when cut free from its adjacent tire. The forces such as those of tension in the ring, those of torsion which would tend to turn the ring about its own inertia axis, and those of shear which would prevent its free rotation about and axis perpendicular to the plane of the ring at the center of its circumference. The results of this method are as follows
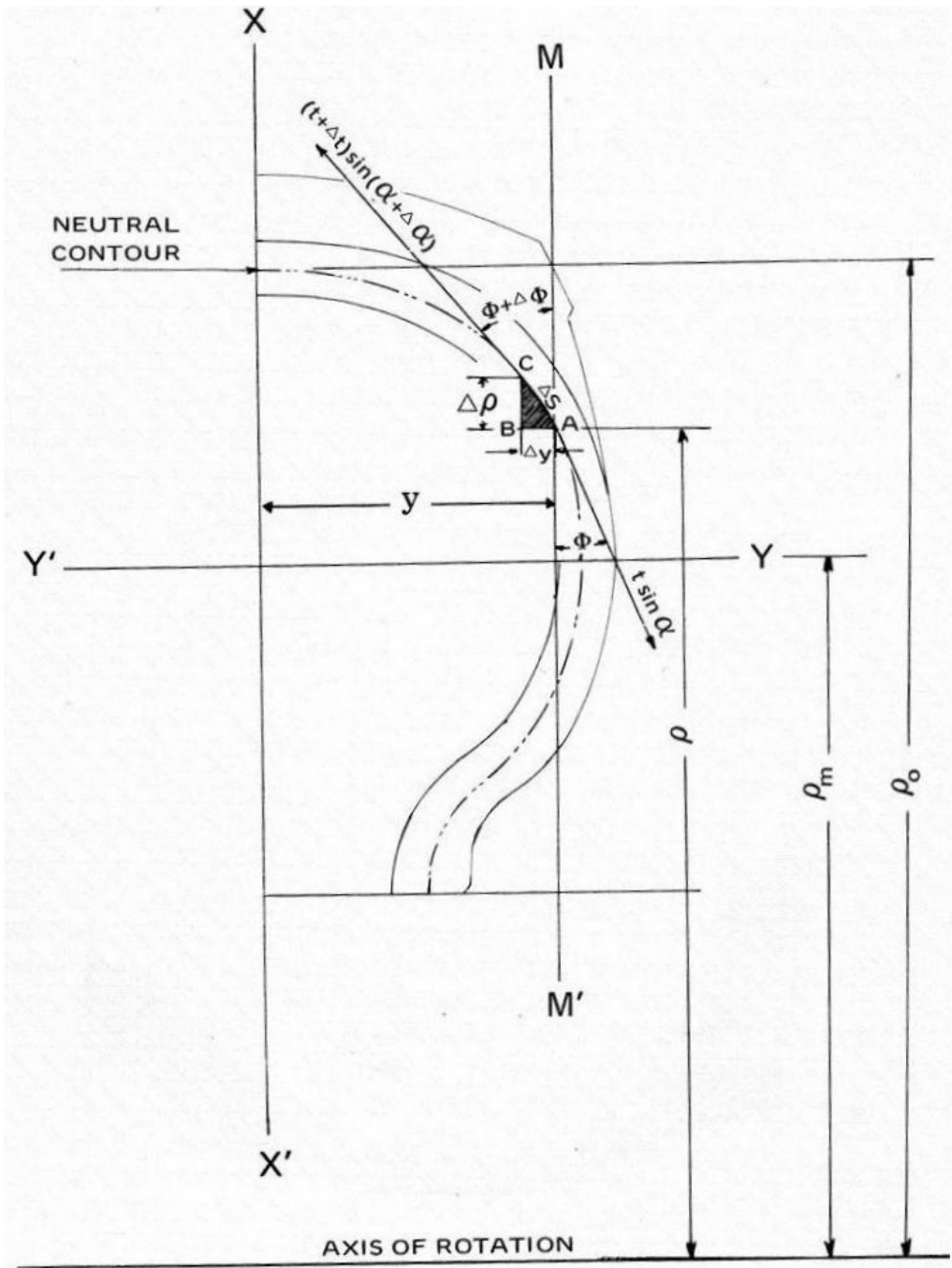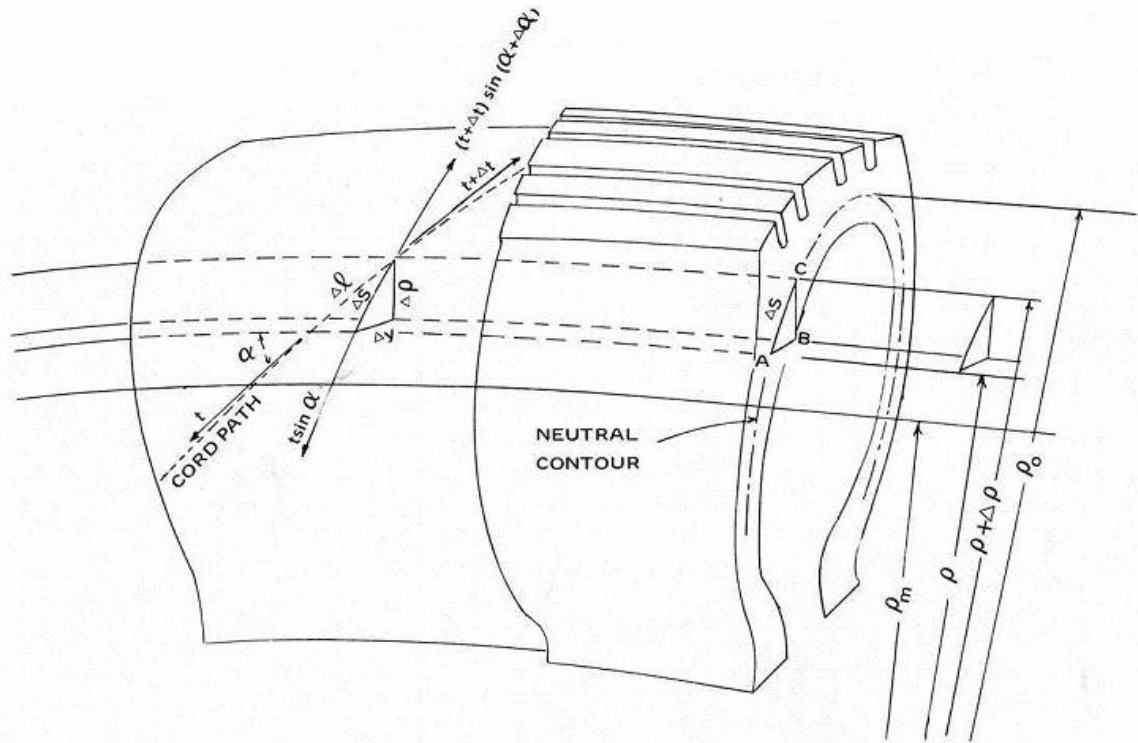
**Figure 3-1 Tire Bead Cross-Section**

Figure 3-2 Tire Section

Let the dimensions of the elementary ring cut in the plane MM' of Fig:3-1 be Δs, Δy, and $\Delta \rho$. Δs is element of contour-wise length when refereed to the tire contour. The Δy face of the ring lies at the radius ρ from the axis of rotation of the tire of which the ring is a part. Cord angle 'α' is defined as the acute angle which the cord makes with the circumference of a circle of any radius ρ

Point C, Fig: 3-1 lies at a radius $\rho + \Delta \rho$ from the axis of rotation. Pint B lies at a perpendicular distance y from the mid-plane xx' of the tire, and A lies at a distance $y + \Delta y$ from the xx' plane.

If the tire were inflated to pressure 'p', the force acting on the elementary face Δy to create hoop tension in the ring is
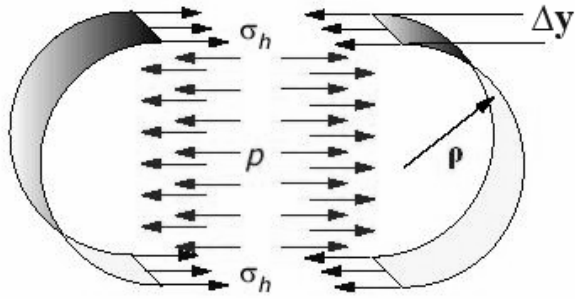
$$\sigma h = 2 p \rho . \Delta y \qquad (1)$$

To prevent the circumferential expansion of the free ring under pressure 'p' on its Δy face, the cords crossing elementary cross-section ABC of Fig-3-1 must have components normal to that cross section.

Let N - Total number of cords in the tire that cross the elementary surface Δ s.

Then number of crossing per unit length of a circle of radius ρ is $\dfrac{N}{2\pi\rho}$ and the number crossing $\Delta\rho$ surface is
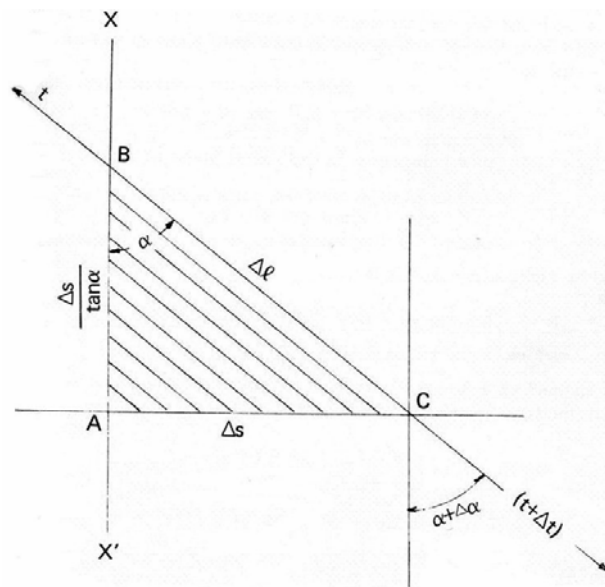
$$\frac{N}{2\pi\rho} \cdot \frac{\Delta s}{\tan \alpha}$$

If 't' is the tension in each cord, its component normal to the cut end ABC of the ring is tcosα and the total force component of cords crossing ABC face of the ring is

$$\frac{2.Nt\cos\alpha.\Delta s}{2.\pi\rho.\tan\alpha} \qquad (2)$$

Equilibrium between (1) and (2) are sufficient to prevent the ring being blown apart by inflation pressure p.

To maintain its position with reference to the tire from which it was cut, the ring must also be free of torsion. Any restraining force to its lateral movement will result in non-uniform tension over its length. Therefore, consider the case of unknown uniform tension along the length of the cord,

At point A of the elementary ring

Let the tension in the cord be at radius ρ be t and cord angle at this point be α. A tangent line to the surface Δs at this point intersects radius ρ at an angle ϕ . The component of the cord tension in a radial plane, that is the component parallel to the Δ ρ face of the ring is

$$t.\sin\alpha.\cos\phi \qquad (3)$$

Let the cord tension at point C be (t+Δ t), the cord angle (α + Δ α) and the contour angle (ϕ+Δϕ). The component of cord tension in radial plane at radius (ρ + Δ ρ) is

$$(t+\Delta t).\sin(\alpha+\Delta\alpha).\cos(\phi+\Delta\phi) \qquad (4)$$

The total force component in the radial plane at radius ρ is

$$\frac{N}{2\pi\rho}(t.\sin\alpha.\cos\phi).2\rho \qquad (5)$$

on the radius (ρ + Δ ρ) is

$$\frac{N(t+\Delta t).\sin(\alpha+\Delta\alpha).\cos(\phi+\Delta\phi).2.(\rho+\Delta\rho)}{2.\pi(\rho+\Delta\rho)} \qquad (6)$$

To expand expression (6), neglect infinitesimals of higher order than the first, and remembering that

$$\cos \Delta\alpha \to 1 \quad as \;\; \Delta\alpha \to 0$$
$$\cos \Delta\phi \to 1 \quad as \;\; \Delta\phi \to 0$$
$$\sin \Delta\alpha \to \Delta\alpha \;\; as \;\; \Delta\phi \to 0$$
$$\sin \Delta\phi \to \Delta\phi \;\; as \;\; \Delta\phi \to 0$$

The resulting expression is

$$\frac{N}{\pi}\left(t.\sin \alpha.\cos \phi - t.\sin \alpha.\sin \phi.\Delta\phi + t.\cos \alpha.\cos \phi.\Delta\alpha + \sin \alpha.\cos \phi.\Delta t\right) \quad (7)$$

The free ring is in equilibrium under forces of tension and torsion when the sum of expressions (1),(2),(5),(7) are equal to zero.

$$\left.\begin{cases} 2p\rho\Delta y - \dfrac{N.t.\cos \alpha.\Delta s}{\pi.\rho.\tan \alpha} - \dfrac{N.t.\sin \alpha.\cos .\phi}{\pi} + \\[3mm] \dfrac{N}{\pi}\left[t.\sin \alpha.\cos \phi - t.\sin \phi.\Delta\phi - t.\sin \alpha.\sin \phi.\Delta\phi + t.\cos \phi.\cos \alpha.\Delta\alpha + \sin \alpha.\cos \phi.\Delta t\right] \end{cases}\right\} = 0$$

Which, on combining terms becomes

$$\left.\begin{cases} 2p\rho.\Delta y - \dfrac{N.t.\cos \alpha.\Delta s}{\pi.\rho.\tan \alpha} + \\[3mm] \dfrac{N}{\pi}\left[t.\cos \alpha.\cos \phi.\Delta\phi - t.\sin \alpha.\sin \phi.\Delta\phi + \sin \alpha.\cos \phi.\Delta t\right] \end{cases}\right\} = 0 \qquad (8)$$

An examination within brackets of the expression (8) shows that it is exactly

$d\left(t.\sin \alpha.\cos \phi\right)$

Dividing expression (8) by Δs and passing to the limit

$$\frac{2.\pi.p.\rho}{N}.\frac{dy}{ds} + \frac{d}{ds}\left(t.\sin \alpha.\cos \phi\right) - \frac{t.\cos \alpha}{\rho.\tan \alpha} = 0 \qquad (9)$$

Since the values of t and p are unknown as yet, they must be eliminated from equation (9). Without the loss of generality, consider a circular ring having its inner face at radius ρ_m and its outer face at radius $\rho > \rho_m$. The force acting on the surface between radii ρ and ρ_m due to internal pressure p is

$$\pi p \left(\rho^2 - \rho_m^2 \right)$$

The component of cord tension acting in a direction parallel to the yy' axis is $t.\sin\alpha.\sin\phi$ and with N equal to the total number of cords crossing the Δ s face

$$\pi p \left(\rho^2 - \rho_m^2 \right) = N.t.\sin\alpha.\sin\phi$$

so that

$$t = \frac{\pi\, p}{N}.\frac{\left(\rho^2 - \rho_m^2 \right)}{\sin\alpha.\sin\phi} \qquad (10)$$

ρ_m is not always less than ρ if we take the convention that ϕ is positive when $\rho > \rho_m$ and negative when $\rho < \rho_m$.

With equation (10), equation (9) can be written as

$$\left\{ \frac{2\pi.p.\rho}{N}\frac{dy}{ds} + \frac{d}{ds}\left(\frac{\pi.p}{N}\frac{\left(\rho^2 - \rho_m^2\right)}{\sin\alpha.\sin\phi}.\sin\alpha.\cos\phi \right) - \frac{\pi.p}{N}.\frac{\left(\rho^2 - \rho_m^2\right)}{\sin\alpha.\sin\phi}.\frac{\cos\alpha}{\rho.\tan\alpha} \right\} = 0 \qquad (11)$$

Referring figs:3-1 and 3-2 we note that

$$\frac{dy}{ds} = \sin\phi$$

$$\frac{d\rho}{ds} = \cos\phi$$

$$\frac{dy}{d\rho} = \tan\phi$$

Equation (11) can be written as

$$2.\rho.\frac{dy}{ds} + \frac{d}{ds}\left[\left(\rho^2 - \rho_m^2\right)\frac{d\rho}{dy} \right] - \frac{\left(\rho^2 - \rho_m^2\right)}{\rho}.\frac{\cos^2\alpha}{\sin^2\alpha}.\frac{ds}{dy} = 0 \qquad (12)$$

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This is the differential equation of the contour shape of any tire in terms of its dimensions and cord path.

To solve a differential equation is to reduce it to integral form. Equation (12) can be written as

$$2\rho.dy + d\left[\frac{\left(\rho^2 - \rho_m^2\right)}{\frac{dy}{d\rho}}\right] - \frac{\left(\rho^2 - \rho_m^2\right)}{\rho} \cdot \frac{\cos^2\alpha}{\sin^2\alpha} \cdot \frac{\left(d\rho^2 + dy^2\right)}{dy} = 0$$

Let $\dfrac{dy}{d\rho}$ be denoted by y' for convenience, Therefore last equation can be written

as

$$\left\{2\rho y' d\rho + \left[\frac{2\rho d\rho}{y'} - \frac{\left(\rho^2 - \rho_m^2\right) dy'}{y'^2}\right] - \frac{\left(\rho^2 - \rho_m^2\right)\cot^2\alpha}{\rho} \cdot \frac{1 + y'^2}{y'} \cdot d\rho\right\} = 0$$

or $$\left\{2\rho.d\rho.\frac{1 + y'^2}{y'} + \frac{\left(\rho^2 - \rho_m^2\right) dy'}{y'^2} - \frac{\left(\rho^2 - \rho_m^2\right)\cot^2\alpha}{\rho} \cdot \frac{1 + y'^2}{y'}.d\rho\right\} = 0$$

or as $$\left[\frac{2\rho.d\rho}{\left(\rho^2 - \rho_m^2\right)} - \frac{dy'}{y'\left(y'^2 + 1\right)} - \frac{\cot^2\alpha.d\rho}{\rho}\right] = 0 \qquad (13)$$

Integrating equation (13) between the limits ρ_o and ρ

$$\left\{\left[-\log_e\left(\rho^2 - \rho_m^2\right)\right]_\rho^{\rho_o} + \left[\log_e\frac{y'}{\sqrt{1 + y'^2}}\right]_{y'}^\infty + \int\limits_\rho^{\rho_o}\frac{\cot^2\alpha}{\rho}.d\rho\right\} = 0$$

Substituting back y'= $\dfrac{dy}{d\rho}$

$$\left(\frac{dy}{d\rho}\right)^2 = \frac{\left(\rho^2 - \rho_m^2\right)^2 \left[e^{2\int_\rho^{\rho_o}\frac{\cot^2\alpha}{\rho}d\rho}\right]}{\left(\rho_o^2 - \rho_m^2\right)^2}\left[1 + \left(\frac{dy}{d\rho}\right)^2\right]$$

Dividing through by $\left(\dfrac{dy}{d\rho}\right)^2$

$$1 = \frac{\left(\rho^2 - \rho_m^2\right)^2 \left[e^{2\int_\rho^{\rho_o}\frac{\cot^2\alpha}{\rho}d\rho}\right]}{\left(\rho_o^2 - \rho_m^2\right)^2}\left[\left(\frac{d\rho}{dy}\right)^2 + 1\right]$$

Which by, transposing and inverting the fractions, becomes

$$\left(\frac{dy}{d\rho}\right)^2 = \frac{\left(\rho^2 - \rho_m^2\right)^2 \left[e^{2\int_\rho^{\rho_o}\frac{\cot^2\alpha}{\rho}d\rho}\right]}{\left(\rho_o^2 - \rho_m^2\right)^2} \Bigg/ \left[1 - \frac{\left(\rho^2 - \rho_m^2\right)^2 \left[e^{2\int_\rho^{\rho_o}\frac{\cot^2\alpha}{\rho}d\rho}\right]}{\left(\rho_o^2 - \rho_m^2\right)^2}\right]$$

or
$$\frac{dy}{d\rho} = \frac{-\left(\rho^2 - \rho_m^2\right)^2 e^{\int_\rho^{\rho_o}\frac{\cot^2\alpha}{\rho}d\rho}}{\sqrt{\left(\rho_o^2 - \rho_m^2\right)^2 - \left(\rho^2 - \rho_m^2\right)^2 e^{2\int_\rho^{\rho_o}\frac{\cot^2\alpha}{\rho}.d\rho}}}$$
(14)

Therefore the equations of the contour of any tire in terms of its dimensions and its cord path is

$$y = \int\limits_{\rho}^{\rho_o} \frac{-\left(\rho^2 - \rho_m^2\right)^2 e^{\int\limits_{\rho}^{\rho_o} \frac{\cot^2 \alpha}{\rho} d\rho}}{\sqrt{\left(\rho_o^2 - \rho_m^2\right)^2 - \left(\rho^2 - \rho_m^2\right)^2 e^{2\int\limits_{\rho}^{\rho_o} \frac{\cot^2 \alpha}{\rho} \cdot d\rho}}} \, d\rho \qquad (15)$$

3.1. TENSION DUE TO INFLATION PRESSURE

Cord tension from equation (10) is

$$t = \frac{-\pi p\left(\rho_m^2 - \rho^2\right)}{N.\sin \alpha.\sin \phi}; \quad \rho \geq \rho_m$$

The component of cord tension tangent to the tire contour and in a radial plane is

$$t.\sin \alpha$$

and its component in the plane of any great circle of radius ρ is

$$t.\sin \alpha \cos \phi$$

This component of tension exerted by each cord of the tire results in a uniformly distributed force around a bead of radius ρ to which the piles of a tire are anchored and which serves as a means of holding a tire on a wheel. If n equals the number of tire cords per inch counted normally to the cord path, then over one inch of circumference of the ring of radius ρ there are n sin α cords in each ply.

Let v be the number of piles in a tire. Therefore for v piles the tension in the bead is

$$t n v \, \rho \sin^2 \alpha \cos \phi = T \qquad (16)$$

Substituting value of t into (16), we have

$$T = \frac{-p}{2} \frac{\left(\rho_m^2 - \rho^2\right)\cos\phi}{\sin\phi}; \rho \geq \rho_m$$

$$T = \frac{-p}{2} \frac{\left(\rho_m^2 - \rho^2\right)}{Tan\phi}; \rho \geq \rho_m \qquad (17)$$

Expanding the terms $Tan\phi$ in (17)

$$T = \frac{p\sqrt{\left(\rho_0^2 - \rho_m^2\right)^2 - \left(\rho_m^2 - \rho^2\right)^2 e^{2\int_\rho^{\rho_o} \frac{\cot^2\alpha}{\rho}d\rho}}}{2e^{\int_\rho^{\rho_o} \frac{\cot^2\alpha}{\rho}d\rho}} \qquad (18)$$

For radial tires, the cord angle 'α' is 90. Therefore tension in the bead is

$$T = \frac{p\sqrt{\left(\rho_0^2 - \rho_m^2\right)^2 - \left(\rho_m^2 - \rho^2\right)^2}}{2}$$

In the construction of a tire, the edges of the several piles are anchored to the bead by folding them around the bead and extending the fold to a diameter larger than that of the bead itself, a comparatively rigid structure is formed by the combination of the steel anchor ring and piles of rubberized fabric. If this rigid structure was placed with its neutral contour coinciding with the neutral contour of the flexible tire, as of Fig:3-5, Equation (18) would exactly define the tension in the bead.
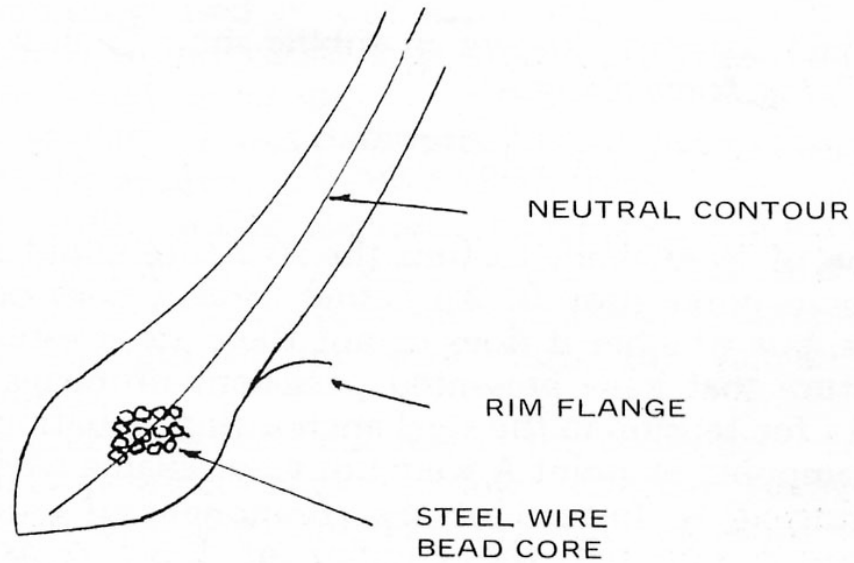
Figure 3-3 Tire and Bead Countours Coincidense(1)

However, In most tires, the rigid structure of the bead and surrounding rubberized cord material is shaped as in fig: 3-6, and the neutral contour of the flexible tire comes no way near the neutral contour of the rigid bead.
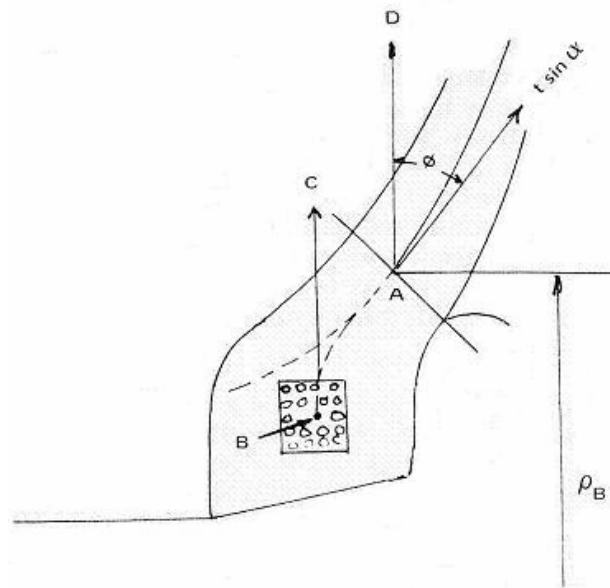
Figure 3-4 Tire and Bead Countours Coincidense(2)

Therefore, in this case equation (16) will be defined at A where flexible contour joins the rigid structure. The force along AD is $tnv\sin^2\alpha\cos\phi$, and in this case bead tends to turn the structure about an axis some point near B. As for the tension in the bead,

equations (17) computed near the point A were not reliable tensions at B. Instead of the component of the cord pulls $t.\sin\alpha.\cos\phi$ consider the component $t.\sin\alpha.$ as being transmitted over the arc AB to exert force BC on the bead on its own plane. The equation (17) is rewritten as

$$T = \frac{p}{2}\frac{\left(\rho_b^2 - \rho_m^2\right)}{\sin\phi_b}.k \qquad (19)$$

k   : Correction factor; correct the manner in which the forces $t.\sin\alpha.$ are transmitted from A to B. If Equation (19) is used without correction factor, the computed tensions in the bead would be some what greater than actual tensions.

Correction factor 'k' can be experimentally determined by measuring the elongation of the bead used in the experimental tires of known dimensions and inflation pressure.

3.2. TENSION DUE TO CENTRIFUGAL FORCE

High speed, common in today's automobiles makes it necessary to consider the effect of centrifugal force on tire beads.

Consider a tire of weight 'W' rotating at a linear velocity 'v' in feet per second. Hoop tension in tire is

$$\frac{W v^2}{2\pi g \bar{\rho}}$$

Where $\bar{\rho}$ is the radius of to the center of gravity of the cross-section from the axis of rotation. This hoop tension could result from an inflation pressure P acting on the cross-sectional areas of the tire in the radial plane, and a projection of that plane of the area of the rim. Let 'a' be the rim width and 'b' be the rim radius. Then the hoop tension due to centrifugal force is

$$\frac{W v^2}{2\pi g \bar{\rho}} = P\left[2\int_{\rho}^{\rho_o} y d\rho + ab\right]$$

where $2\int_{\rho}^{\rho_o} y\,d\rho$ is the area of the cross-section of the air cavity of the tire.

$$P=\frac{W\,v^2}{\pi\,g\,\widehat{\rho}\left[4\int_{\rho}^{\rho_o} y\,d\rho+2\,a\,b\right]} \tag{20}$$

Therefore 'P' may be used in equation (18) to compute the increment tension in the ring due to the centrifugal force. This incremental tension is additional to that due to inflation pressure. In an race car, at higher speeds depending on size and structural features make the increment of bead ring tension due to centrifugal force equivalent to the increment due to inflation pressure.

3.3. TENSION DUE TO DRIVING OR BRAKING TORQUE

The tensions due to inflation and to centrifugal force are the principal tensions that are placed on a tire bead rings. Driving or braking torque usually does not add a large tension force to the beads of vehicle tires on the highway.

If 'L' is the tire load and 'μ' the tractive coefficient, and r_1 the loaded radius of the tire. Then incremental tension due to Driving load is

$$T=\frac{\mu\,L\,r_1}{2\,\rho_b}$$

4. TIRE BEAD MODELING

Chapter-IV

4.1. PURPOSE

The main objective of this part of the thesis is the selection of the commercially available Finite element software and the assumptions, input data in modeling of weftless and single wire tire beads.

4.2. FINITE ELEMENT SOFTWARE

Finite element analysis is a powerful numerical technique used to quantify the structural integrity of a component. The analysis is done by modeling the structure into thousands of small pieces called finite elements and determining the structures response by simulation various loads such as static, dynamic and temperatures. It offers many advantages over hand calculations and mechanical testing. Hand calculations provide accurate results but are typically useful for only simple geometries. Mechanical testing is often expensive and does not provide the stress at each point of the structure. FEA has been the tool of choice for technical evaluation over the last 20 years. It is a very accurate tool used for failure analysis purposes. It is used to quantify design defects, fatigue, buckling, and code compliance and also to distinguish between failures due to design deficiencies, materials defects, fabrication errors, and abusive use. Several commercial software are available for FE analysis. ANSYS is one of the most widely used general purpose software for FEA. The main advantages of using ANSYS software in this analysis is its simplicity in modeling and evaluation of complex geometries. The three steps in ANSYS are the preprocessor, solution and post processor.

4.3. MODELING THE TIRE BEAD IN ANSYS:

Modeling is one of the most important areas of the finite element analysis. Accuracy in the modeling of the geometry loads, material properties, boundary and other

structural properties are of absolute necessary for close numerical idealization of the of the actual structure. ANSYS offers various solid, plane and line elements which can be used to model rubber and bead wires respectively. The choice depends on the type and geometry of the member.

Tire bead in this investigation is being modeled by using a direct generation method in which the location of the every node, size, shape and element connectivity, in contrast to a solid model where the geometric boundaries of the model and controls over the size and desired shape of the elements are defined. Direct generation method provides with complete control over the geometry and numbering of every node and element Tire bead modeled in this investigation is for a 16 inch wheel tire.

4.2.1 WEFTLESS TIRE BEAD MODELING

Weftless tire bead is composed of link8 and solid45 elements. Weftless tire bead is generated in cylindrical coordinate system. First the nodes are created at every one degree of cylindrical global coordinate system at 8 inch radius for the geometry shown in figure 4.1 below. The distance between the centers of the two steel wires in a weftless tire bead are approximated to be 0.4. Weftless tape is represented in ANSYS by creating five parallel nodes at a distance of 0.4 inch distance between nodes along Z-axis.
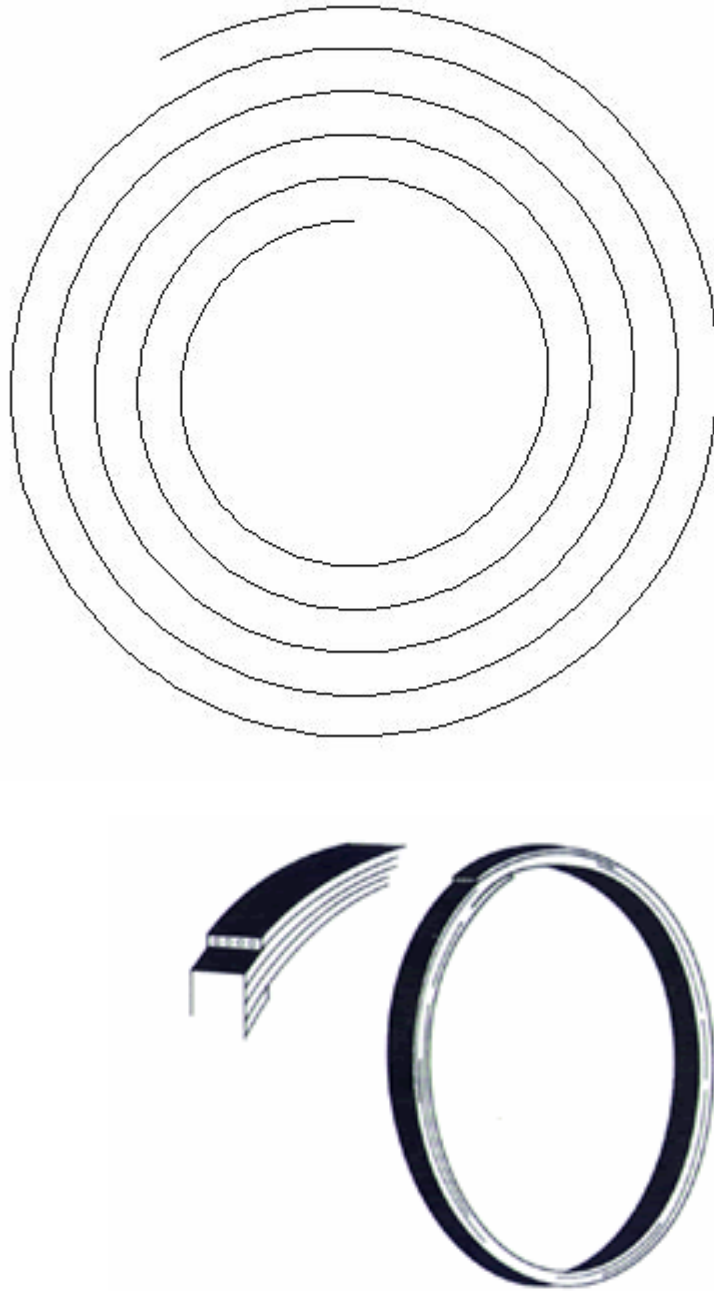
Figure 4-1 Weftless Tire Bead Configuration

The weftless bead nodes created in ANSYS were shown in the figure below.
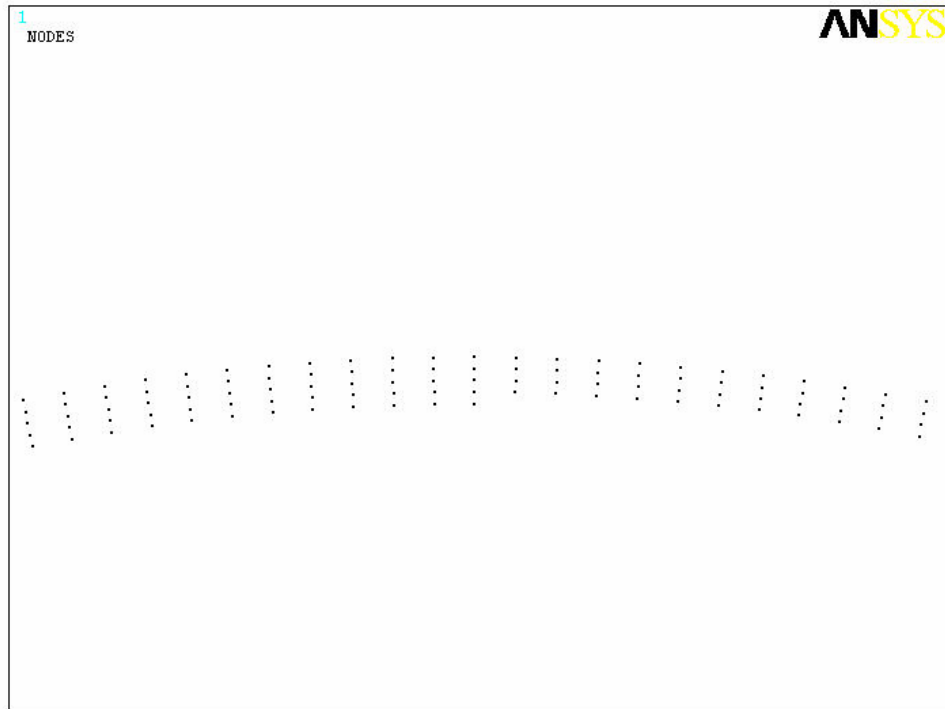
Figure 4-2 Weftless Tire Bead Nodes
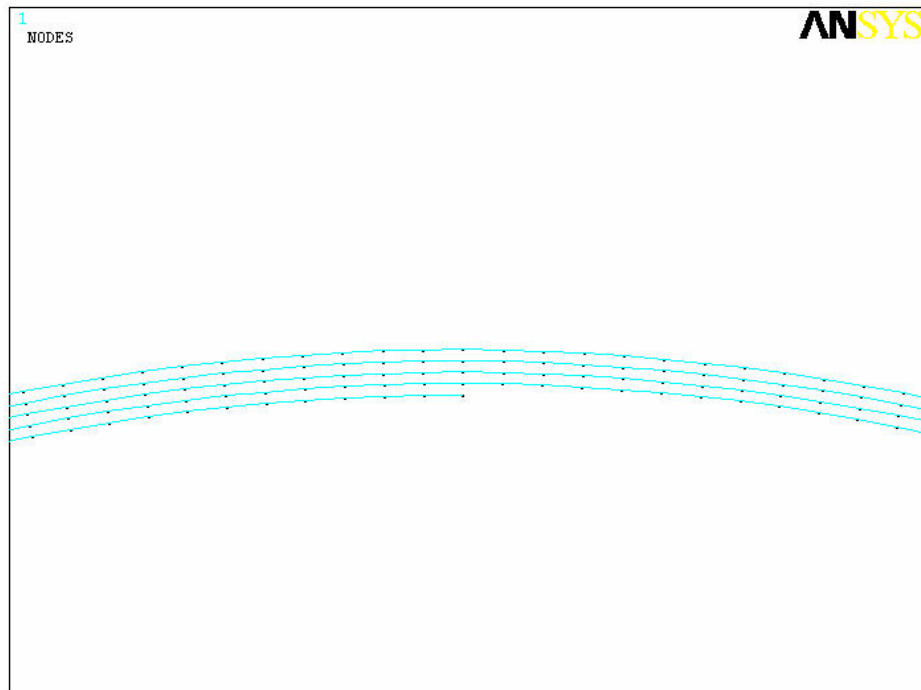
Figure 4-3 Weftless Bead Wire

40

Steel bead wire was represented by creating link8 elements between the nodes. The distance between the centers of the two weftless tapes wounded in a bead grommet was also approximated as 0.4 inch. 360 nodes were created for each single wire loop and a total of 1830 nodes are created for single wire loop with 30 nodes overlap. 9150 nodes were created in ANSYS with 1830 nodes in each XY plane. Rubber material was represented by solid elements. Weftless bead model in ANSYS is shown in the figure below
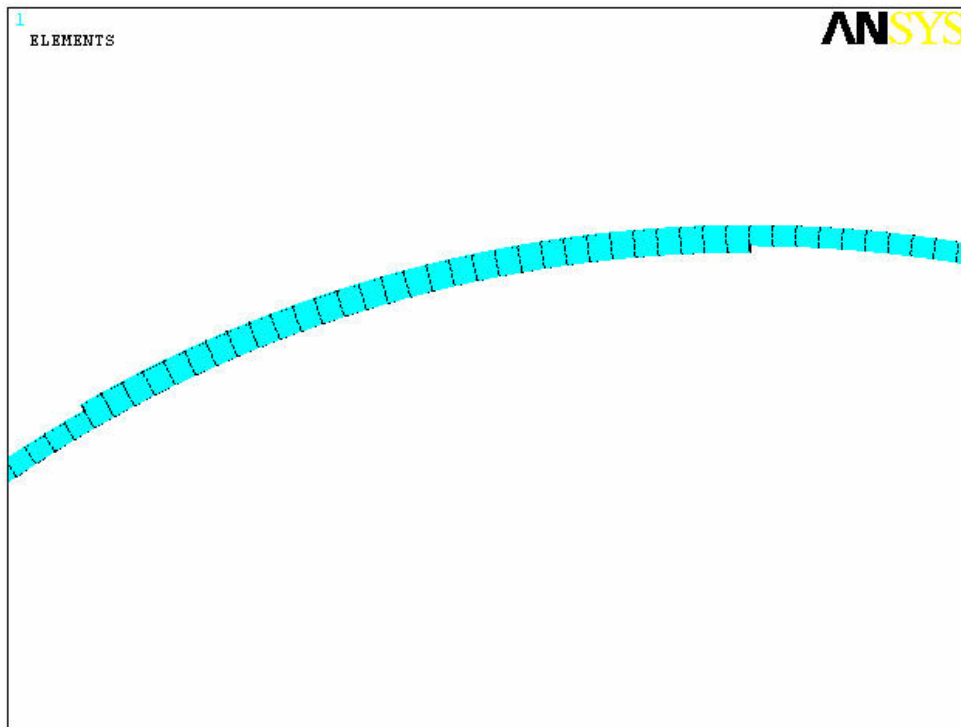
Figure 4-4 Weftless Tire Bead (1)
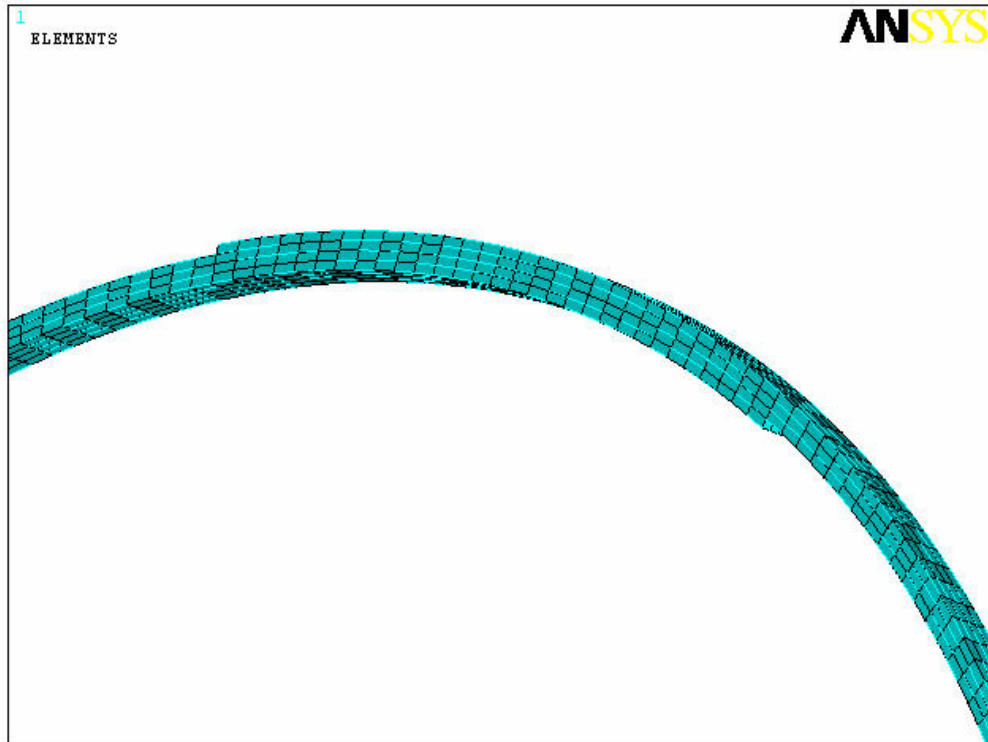
Figure 4-5 Weftless Tire Bead (2)

4.2.2 SINGLE WIRE CONTINUOUS TIRE BEAD

Single wire continuous tire bead grommet is made from a rubber coated wire continuously wound in predetermined turns for required strength as shown in figure 4.6

Figure 4-6 Single Wire Continuous Tire Bead

In ANSYS this single wire continuous tire bead model is simplified and modeled as a 0.037 inch diameter steel wire circular rings. Radiuses of the inner circular rings are approximated as 8 inch with a total of five rings created at a 0.038 inch distance between any two steel wires along circular axis. The centers of second, third and fourth rings from inner rings are approximated as 8.038 inch, 8.076 inch, 8.114 inch and 8.152 inch respectively with a total of 5 rings created at every radius from center of grommet at a 0.038 inch distance between the centers of the any two steel wires along the circular axis as shown in figure 4-7 below
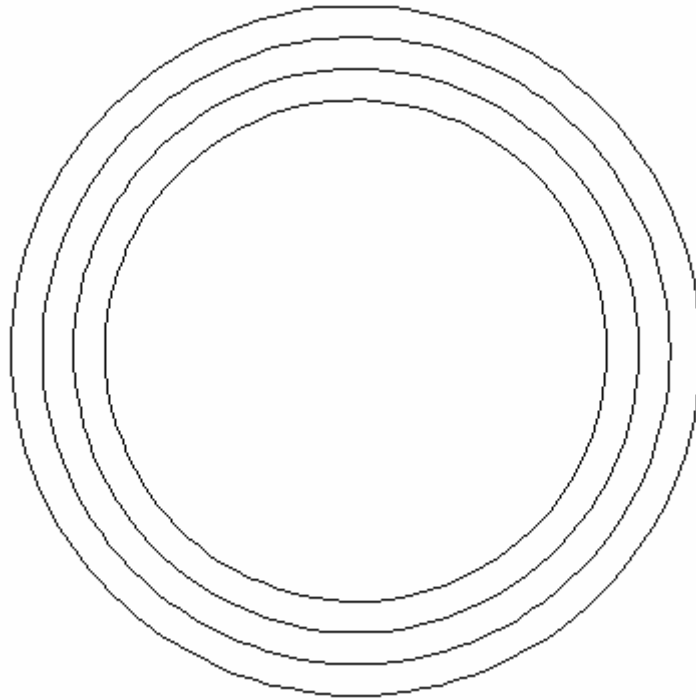
Figure 4-7 Approximated Single Wire Continuous Tire Bead Model

Single wire continuous tire bead in ANSYS is composed of link8 and solid45 elements and it is also generated in cylindrical coordinate system. Element Link8 is represented for bead wire and solid 45 is represented for rubber coating on steel wire. First the nodes are created at every one degree of cylindrical global coordinate system at 8 inch radius for the geometry shown in figure 4.4 below.
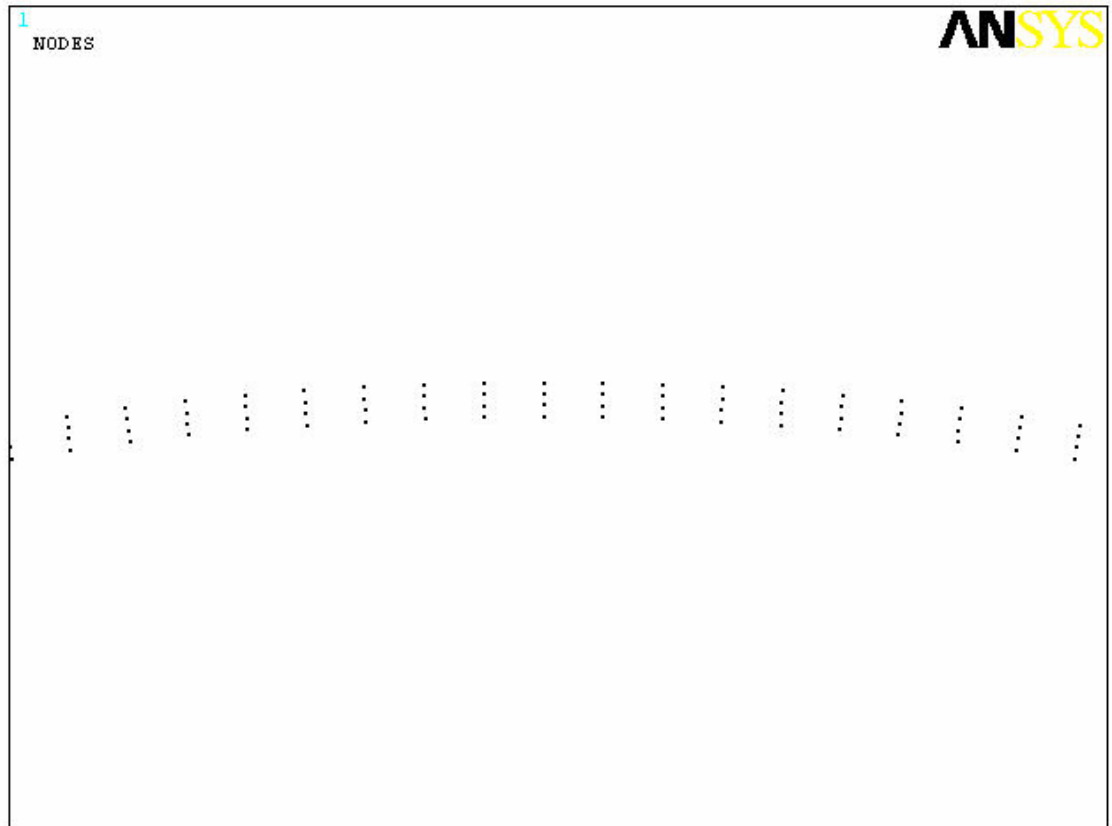
Figure 4-8 Single Wire Continuous Tire Bead Nodes

Total 7200 nodes were created in 20 turns as shown in the figure below. Steel wire in the ANSYS model is represented by a link8 element and the rubber element is represented by a solid45 element in the ANSYS model. Single wire tire bead ANSYS model is shown in the figure 4.9 below.
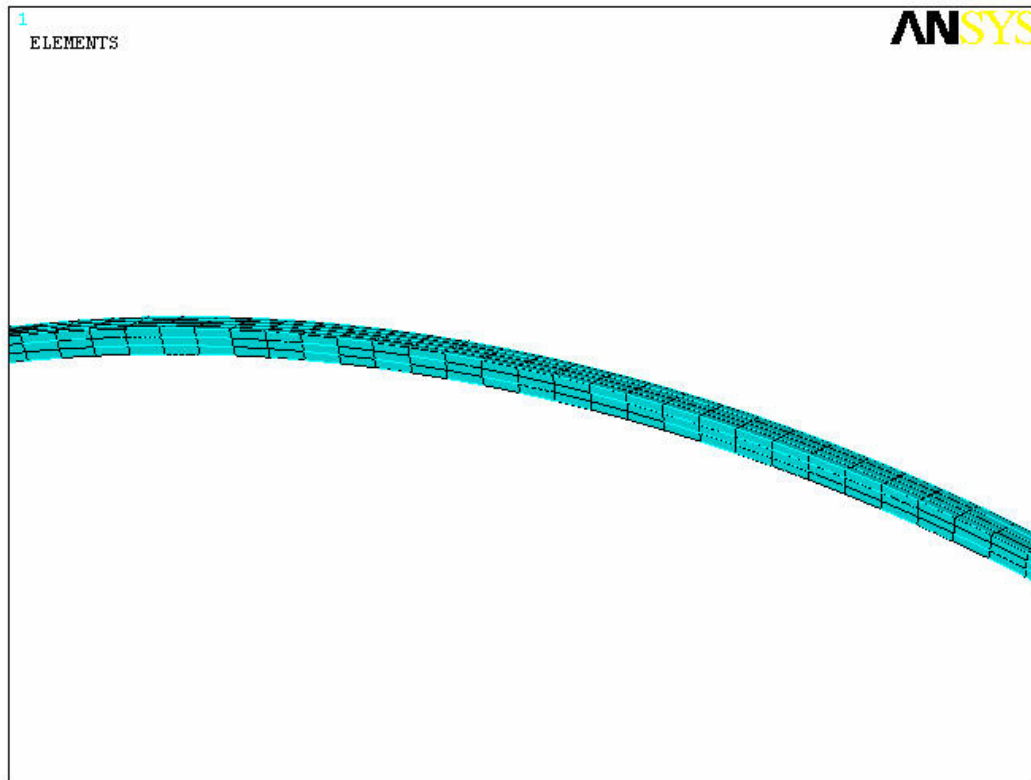
Figure 4-9 Single Wire Continuous Tire Bead

4.4. MATERIAL PROPERTIES

Once the finite element model has been developed, begin considering the assignment of model properties of each finite element. This step is very important as FEA solution can be as good as the representation of real system. Rubber, nylon and work hardened steel is being used to make a tire bead. The materials assumed in this analysis of tire bead are isotropic, properties same in any direction and at any cross section, i.e., independent of geometric orientation and homogeneous, consistent properties throughout the volume. The most useful property available is strength. The units of strength are same as those of stress. Yet, stress in a body is always a function of the applied loading and cross section, strength is an inherent property of the material. Steel wire used in tire bead is a ductile material, almost same tensile and compressive strengths. Rubber is made of brittle material, stronger in compression than in tension. The material properties required by an isotropic linear static analysis are Young's modulus (E), Poisson's ratio (v) and shear modulus (G).

As $E = 2G(1+v)$, therefore providing E, v are sufficient for the analysis.

The young's modulus and poison's ratio of the steel wire and enclosing rubber nylon compound is

Young's modulus of steel wire (link element): 28,000,000 psi

Poisson's ratio of steel wire (link element): 0.3

Young's modulus of rubber compound (solid element): A very thin coating of rubber bonding between the steel wires behaves as properties of nylon or a synthetic material 180,000 psi

Poisson's ratio of rubber nylon compound (solid element): 0.4

4.5. BOUNDARY CONDITIONS

Boundary conditions are the loads and constraints represented in the model that each component or system of components experiences in the working environment that is not explicitly modeled. Loads are used to represent inputs to the system of interest and they can be in the form of forces, moments, pressures, temperatures or accelerations. Constraints on the other hand, are typically used as reactions to the applied loads and they can resist translational or rotational deformation induced by these loads. Boundary conditions here in these models are defined relative to the cylindrical coordinate system.

Some of the assumptions inherent in this boundary condition scheme are summarized below

- The load can be applied as being uniformly distributed both at the instant of its application and any time thereafter
- Any side component of the loads in z direction will be neglected.

Weftless and Single wire tire models in this study are solved with displacement constraints and with pressure loads on the inner side of the tire bead.

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5. RESULTS AND DISCUSSION

CHAPTER-5

5.1. 0.037" WEFTLESS BEAD BEHAVIOR DUE TO INFLATION PRESSURE

Bead has to resist the constant pull created by the inflation pressure of the tire. The body ply of a radial tire consists of steel cords linked together by rubber across the tire from bead to bead. A flat bead surface locks the tire against the rim flange and sealing the air pressure inside the tire like a pressure vessel. Body ply cords actually bend around the beads and come partway up the sidewall of the tire.
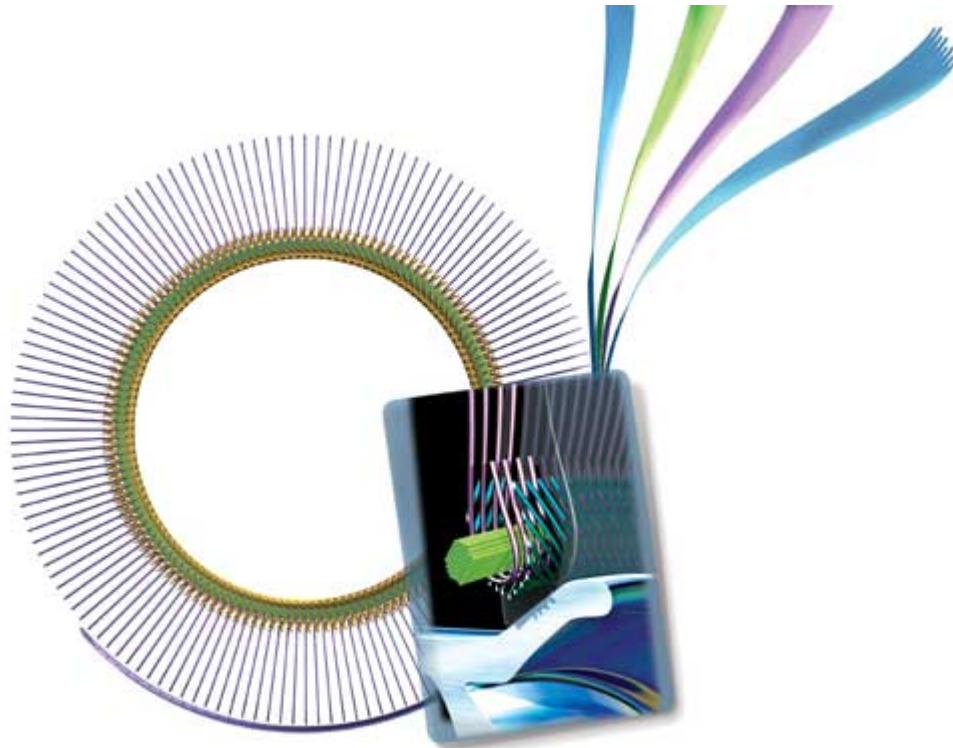
Figure 5-1 Thread Wounding around the Weftless Bead

The tire considered in this analysis is a 16 inch tire with 8" thickness. Maximum Pressure inflated in normal running conditions in a 16 inch truck tire is 50 PSI. Therefore Weftless Bead is analyzed for a uniform pressure of 50 PSI all along the bead

The fig: 5-2 shows the 50 PSI pressure acting along the inner side of the tire bead on the ANSYS tire bead model. The 50 PSI inflation pressure is taken from the normal inflation pressure of the passenger car tire.
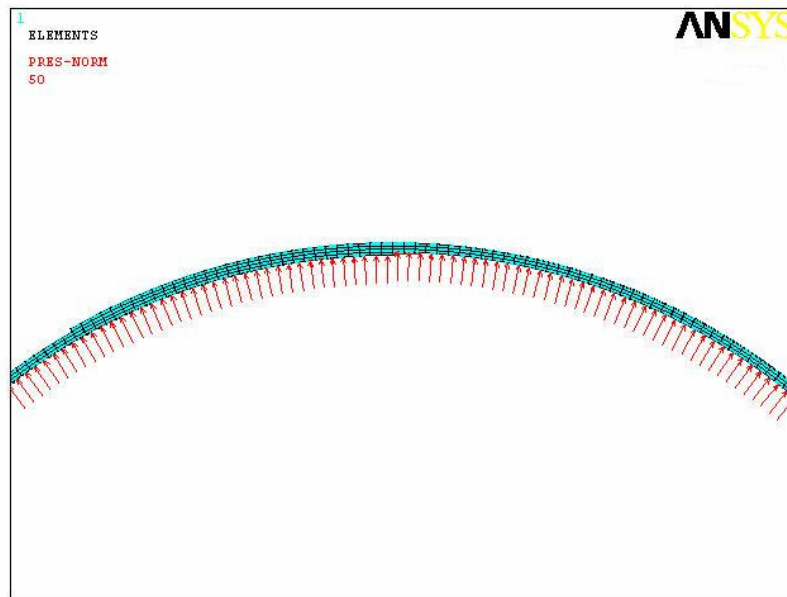
Figure 5-2 50 PSI Pressure Load on 0.037" Weftless Tire Bead
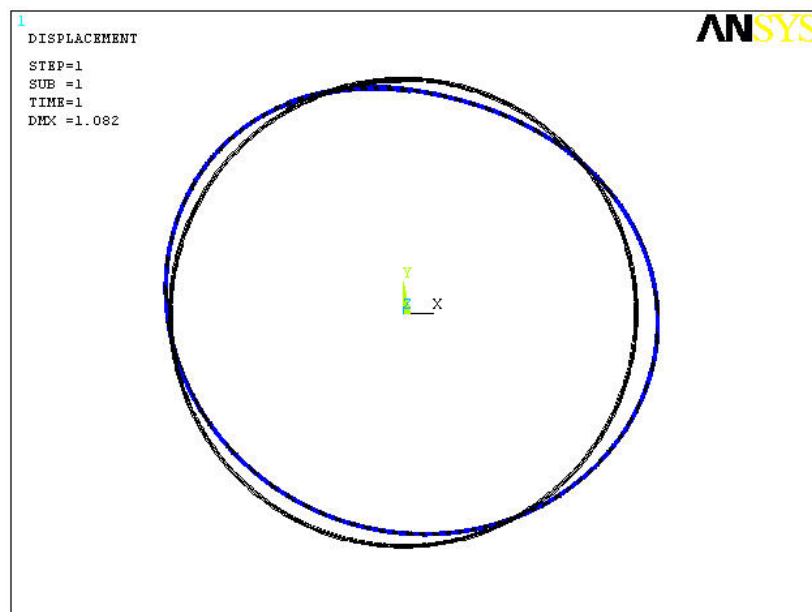
Figure 5-3 Deformed 0.037" Weftless Bead

When 50 PSI pressure is applied all along the inner side of the weftless bead the bead grommet is deformed as shown in the Figure: 5-3. Weftless Bead is deformed to an elliptical shape with varying radiuses all along the radial direction. The bead is being deformed for a higher radius near the splice end of the weftless bead.
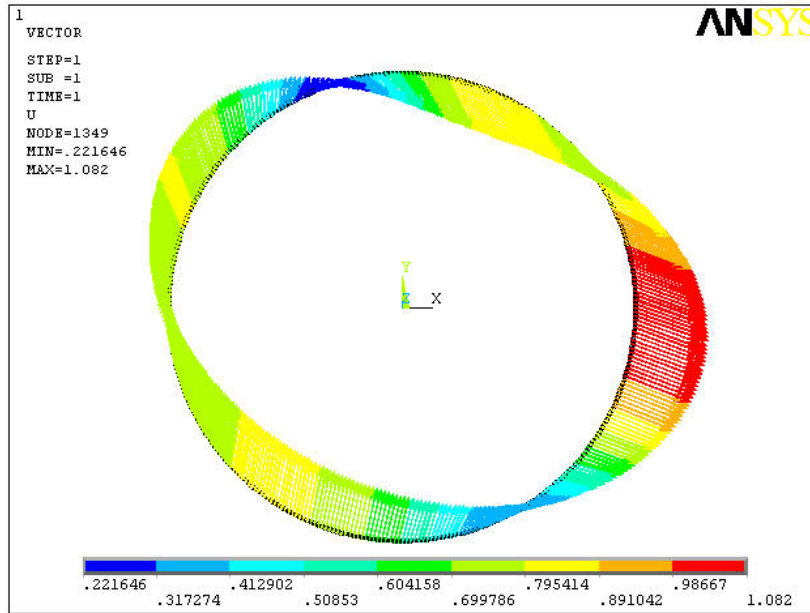
Figure 5-4 Deformed 0.037" Weftless Bead in vector form

Deformed 0.037" Weftless Bead in vector form is shown in Fig: 5-4. Weftless bead is deformed to elliptical shape with a change near the splice area
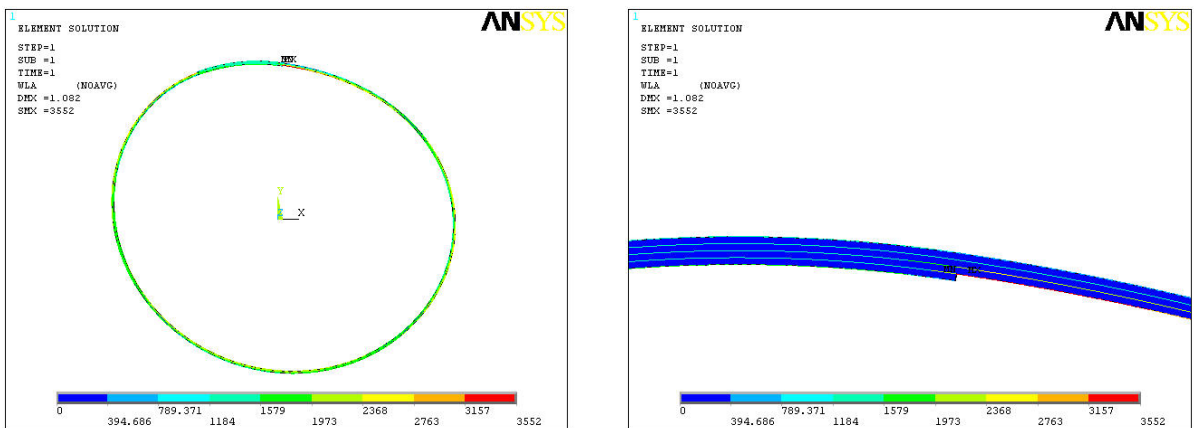

Figure 5-5 Stress on 0.037 Weftless Bead wire due to Pressure Load

49

Maximum Stress resulting from the 0.037" weftless bead wire due to 50 Psi pressure load is shown the Figure: 5-5 with high stress near the splice area.
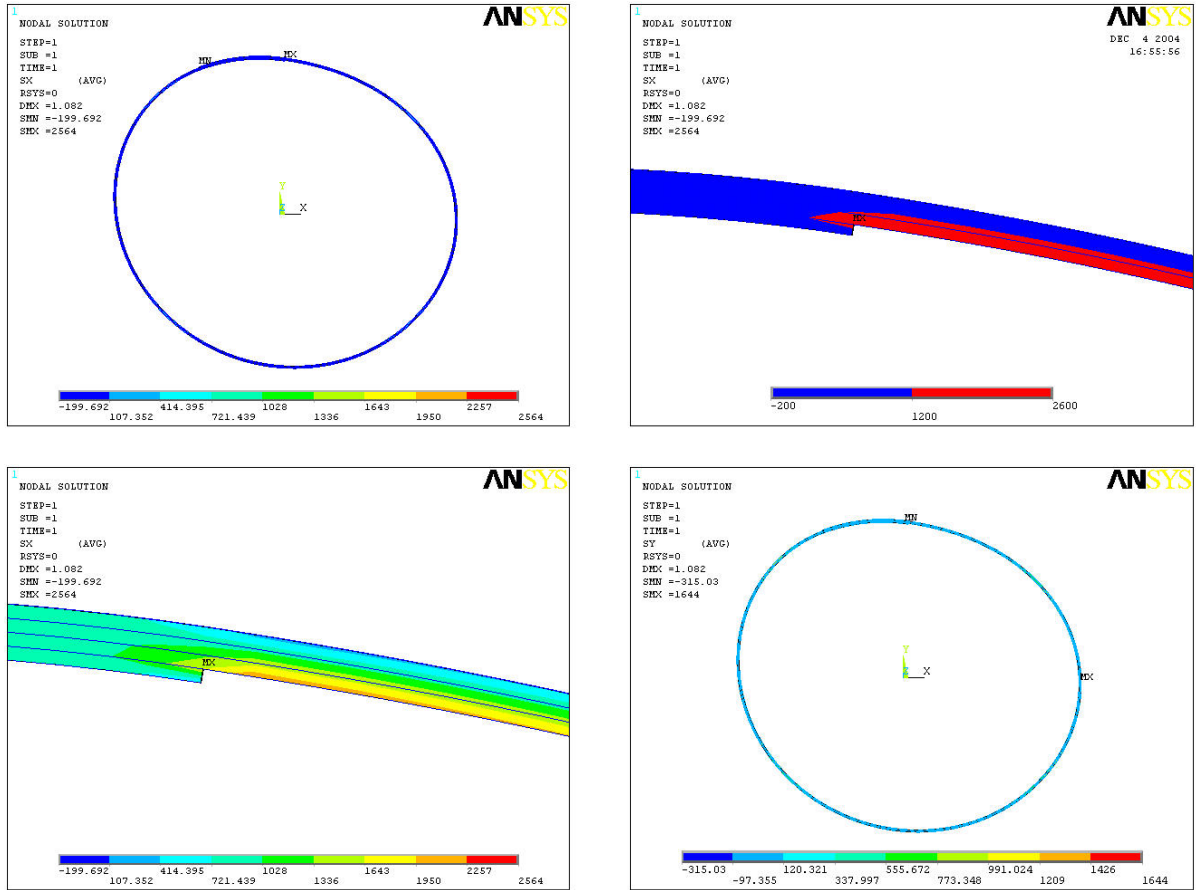
Figure 5-6 SX and SY resulting due to Inflation Pressure on 0.037" Weftless Bead

The maximum stress resulting on the 0.037" weftless bead due to 50 Psi pressure along the X and Y direction is shown in the Figure 5-6. The maximum stress resulting in X direction is 2564 and in Y direction is 1644.
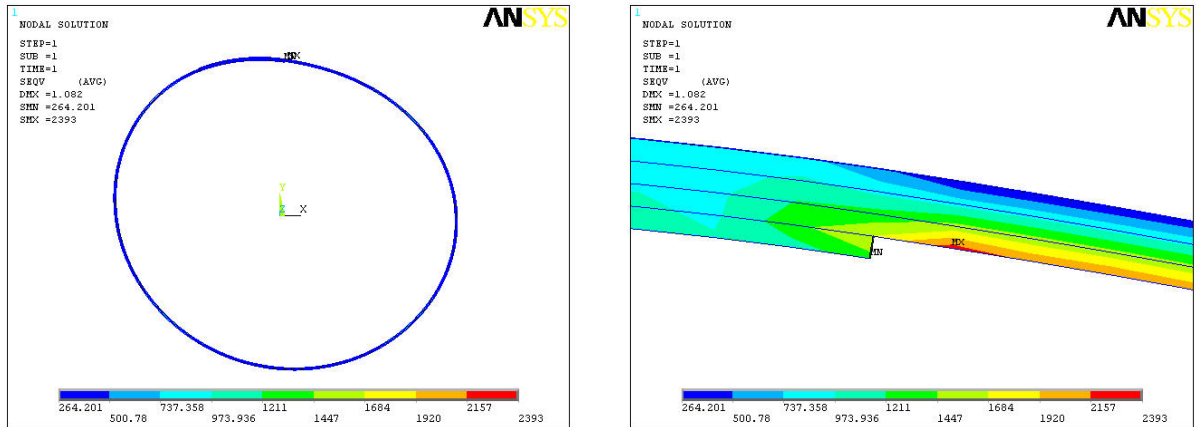
Figure 5-7 Von Misses Stress on 0.037 Weftless Tire Bead due to Pressure Load

Von Misses stress resulting on the 0.037" Weftless Bead due to 50 PSI inflation Pressure is shown in the Fig: 5-7. Maximum stress is occurring at the start of the inner side of the bead grommet due to 50 PSI normal loading pressure and it is 2393 PSI.

Therefore from the above Figures: 5-3 to 5-7 It is concluded that maximum stress on the 0.037" bead wires for normal inflation pressure is always occurs near the starting of the inner splice area. Therefore Splice in 0.037"diameter Weftless bead is always the weakest point and prone to separation. Flexural rigidity of the 0.037" weftless bead is not uniform and a shows a high concentrated region near the splice area. If tire is not properly mounted onto the wheel results in higher stress near the vicinity of the splice resulting in one or two wires carrying the whole stress of the bead grommet resulting in failure of the grommet.

5.2.0.51" WEFTLESS BEAD BEHAVOIR DUE TO NORMAL INFLATION PRESSURE
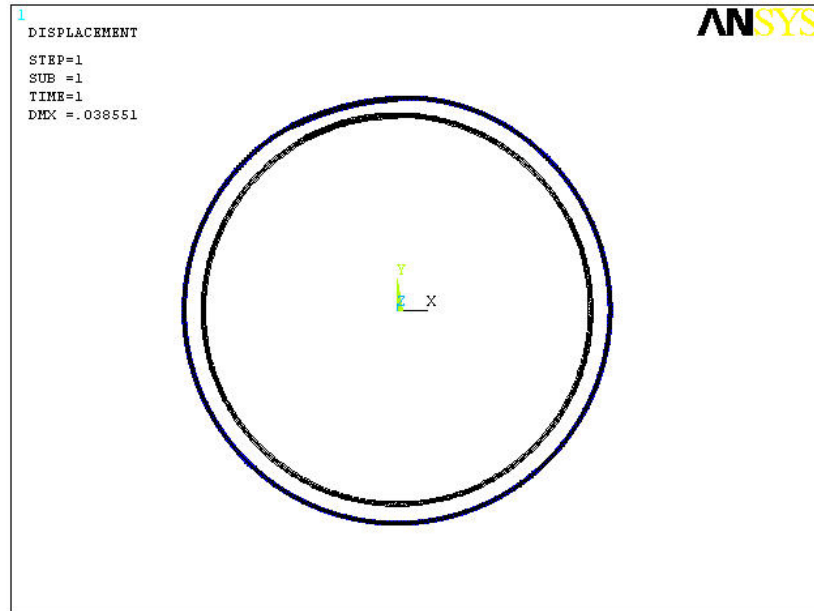
Figure 5-8 Deformed 0.051" Weftless Bead

Deformed shape of the 0.051" Weftless Bead Grommet due to 50 PSI pressure all along the inner side of the bead is shown in figure: 5-8. 0.051" Weftless Bead is deformed with uniform radius all along the Bead. Deformation due to the inflation pressure in 0.051" Weftless Bead is 0.038551, less than 0.037" Weftless bead deformation. Figure 5-9 shows the vector form of the 0.051" Weftless Bead. 0.051" Weftless bead is uniformly deformed all along the radial direction.
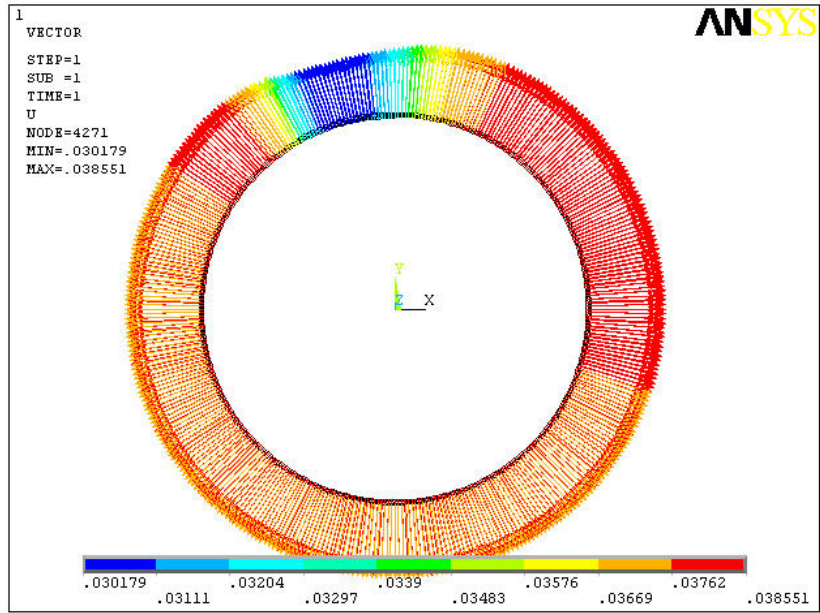
Figure 5-9 Vector Representation of Deformed 0.051" Weftless Bead
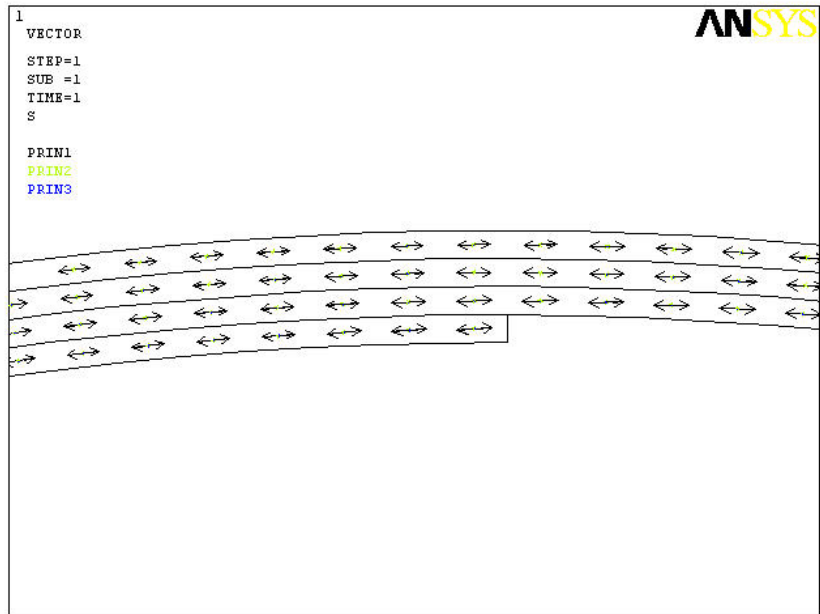
Figure 5-10 Tension on the Bead wires

Figure: 5-10 shows that force acting on the weftless bead due to 50 PSI Inflation pressure is tension all along the bead.
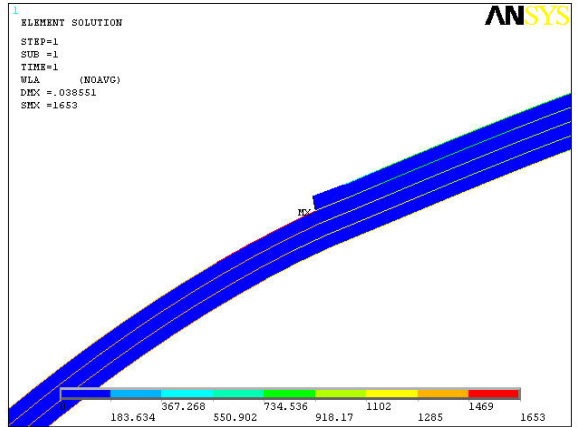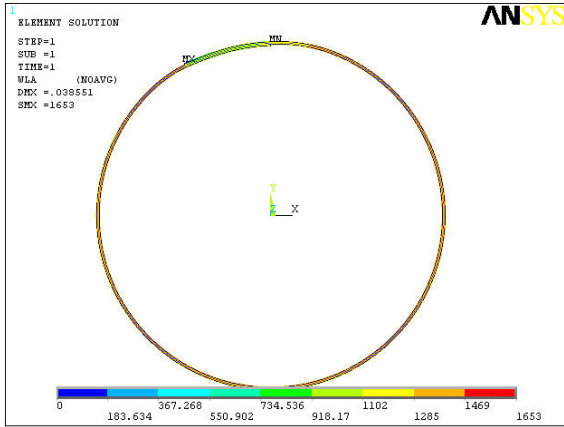
Figure 5-11 Stress on 0.051" Weftless Bead due to Pressure Load

Maximum stress resulting from 50 PSI Inflation Pressure on 0.051" Weftless bead is shown in figure: 5-11 and it is 1653 lb/in². Maximum Stress in 0.051" Weftless Bead is not occurring at the inner end of the splice area and it is occurring at outer end of the splice. Therefore splice is not the weakest point in 0.051" Weftless Bead.
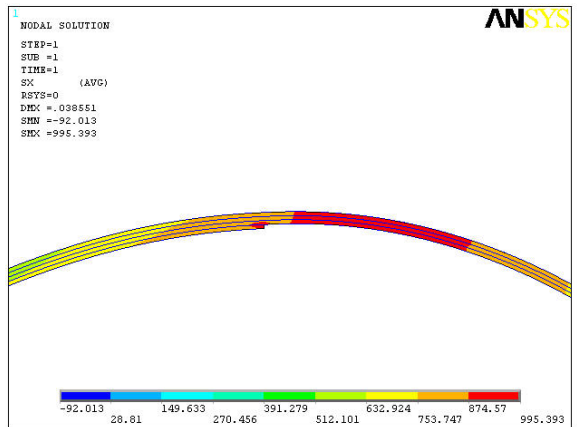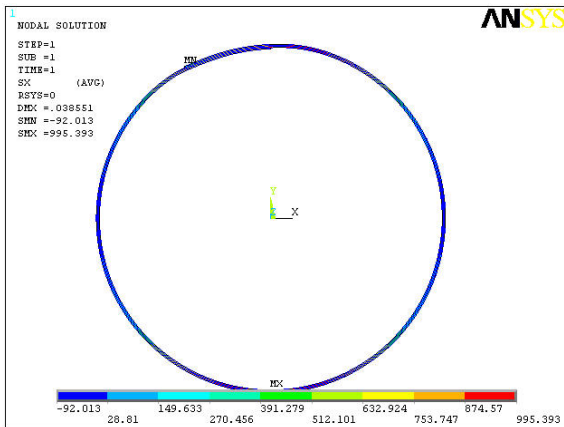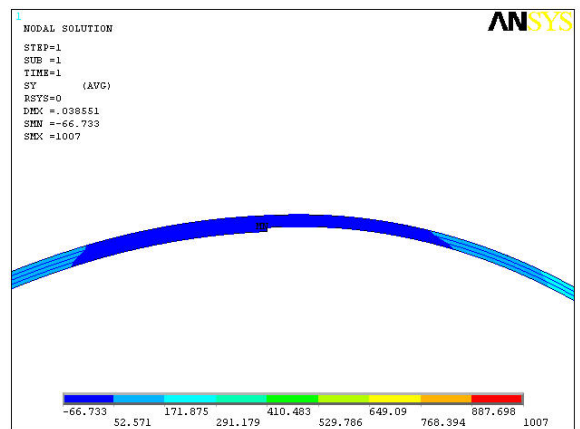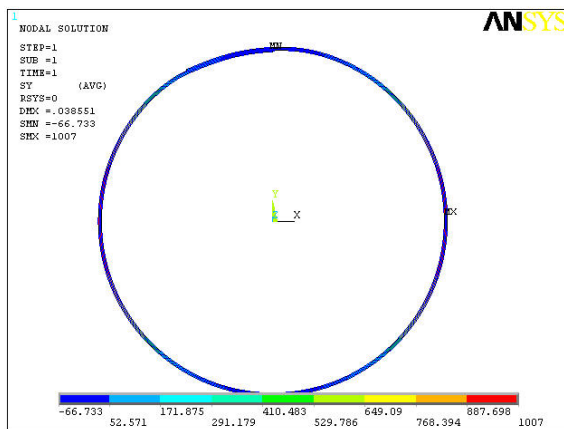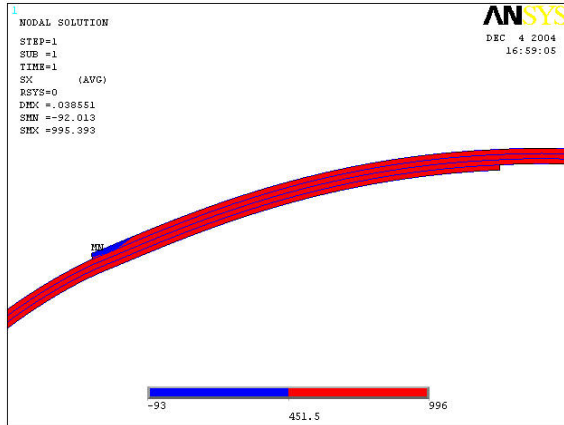
Figure 5-12 Stress in X and Y direction due to Inflation Pressure on 0.051" Weftless Bead

Maximum stress resulting in the 0.051' weftless bead in the X and Y direction due to 50 PSI inflation pressure is shown in figure: 5-12. In 0.051" weftless bead the stress ratio near the inner end of the splice area is less than the 0.037" weftless bead. Therefore Splice of 0.051" weftless bead is not the weakest point as in 0.037" weftless bead.
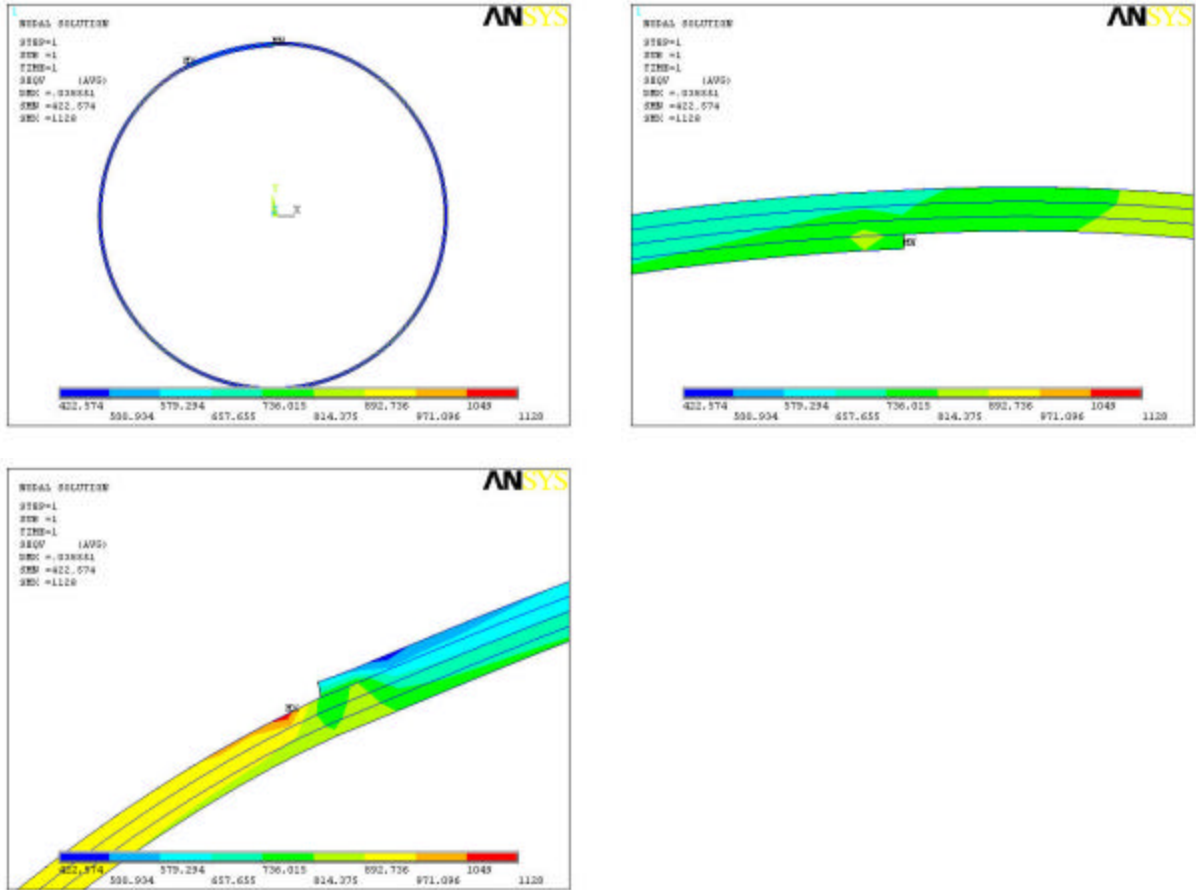
Figure 5-13 Von Misses stress resulting from the 50 PSI inflaton pressure on 0.051" Weftless Bead

Von Misses stress resulting on the 0.051" Weftless Bead due to 50 PSI inflation pressure is shown in figure:5-13. Maximum Von Misses stress in 0.051" Weftless Bead is not occurring at the inner end of the splice and it is occurring at the outer end of the bead.

Therefore from above figures: 5-8 to 5-13 It is concluded that splice is not the weakest point in the 0.051" weftless bead due to inflation pressure. By increasing bead wire diameter from 0.037" to 0.051" increases the strength of the bead by 80% and strengthening the bead wire near the splice area.

5.3. CONTINUOUS SINGLE WIRE BEAD BEHAVOIR DUE TO NORMAL INFLATION PRESSURE
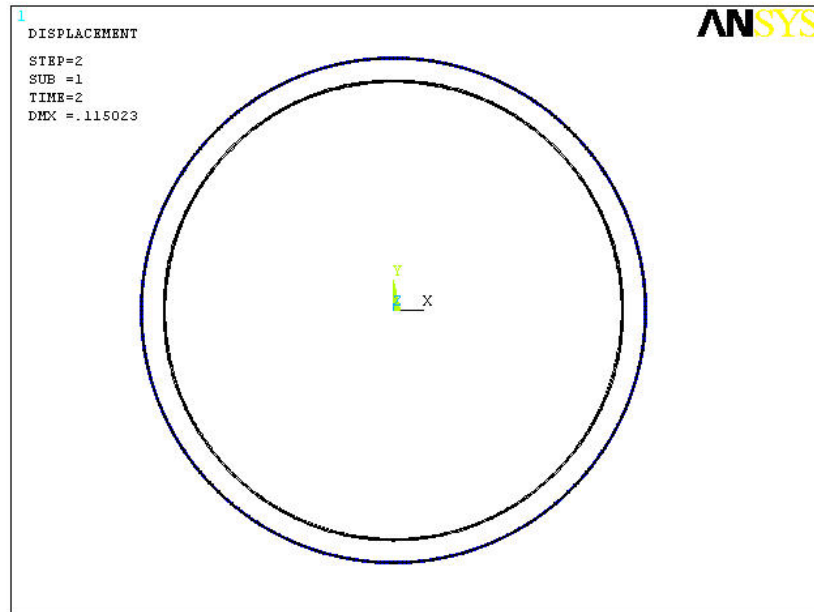
Figure 5-14 Deformed Continuous Single Wire Bead

Deformed shape of the Continuous Single Wire bead grommet due to 50 PSI inflation pressure all along the inner side is shown in the figure: 5-14. It is deformed with uniform radius all along the bead. Deformation due to normal inflation pressure is .114353, far less than the 0.037" weftless bead. Deformation in vector form is show in the figure: 5-15
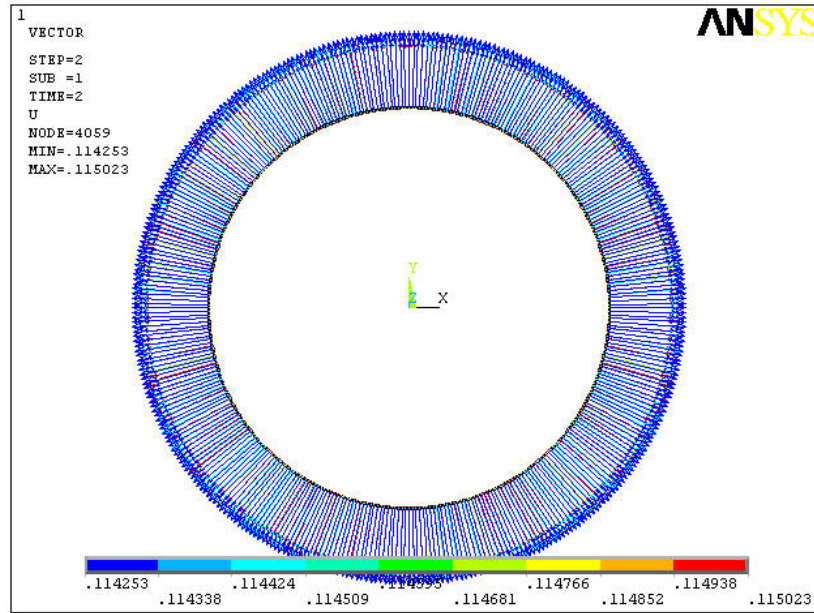
Figure 5-15 Deformed Continuous Single Wire Bead in vector form
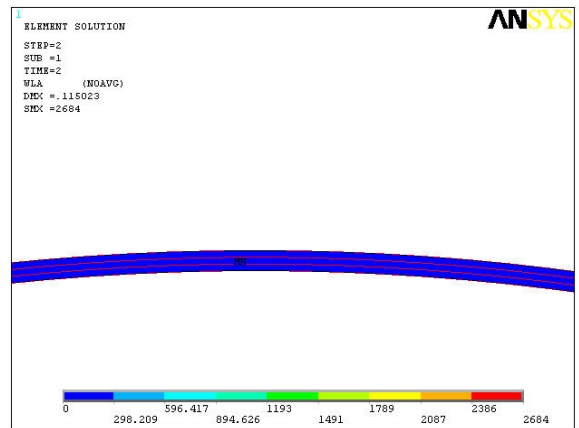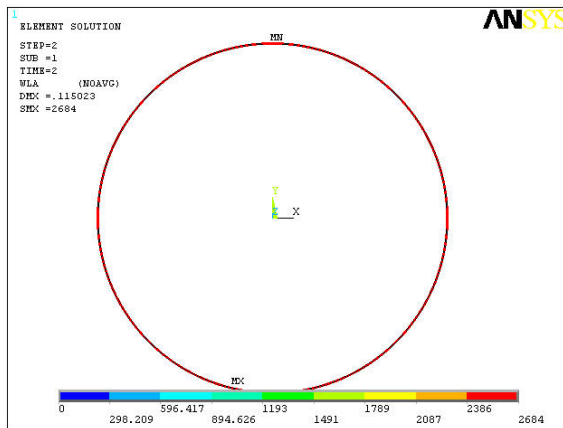
Figure 5-16 Stress on Continuous Single Wire Bead due to Pressure Load

Maximum stress resulting from 50 PSI Inflation Pressure on Continuous Single Wire Bead is shown in figure: 5-16 and it is 2684 lb/in2. The Stress resulting in the Continuous Single Wire Bead is uniformly distributed in the Bead grommet.
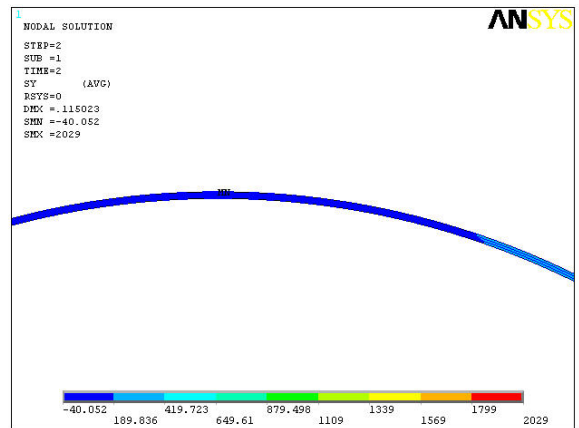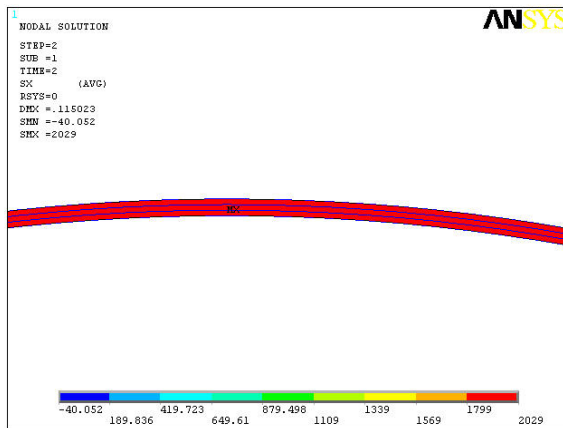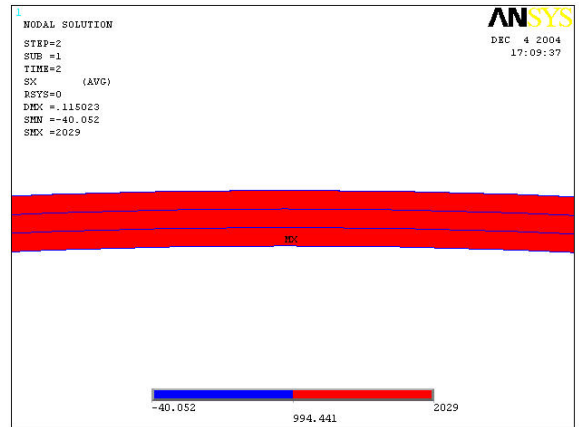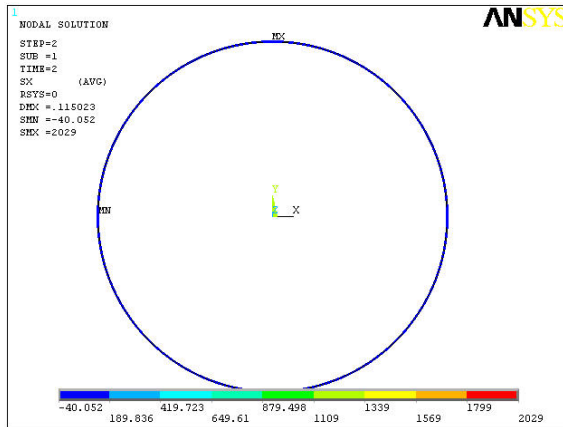
Figure 5-17 Stress in X and Y direction due to Inflation Pressure on Continuous Single Wire Beads

Maximum stress resulting in the Continuous Single Wire Bead in the X and Y direction due to 50 PSI inflation pressure is shown in figure: 5-17. The stress occurring in the Continuous Single Wire Bead is less than the 0.037" Weftless Bead.
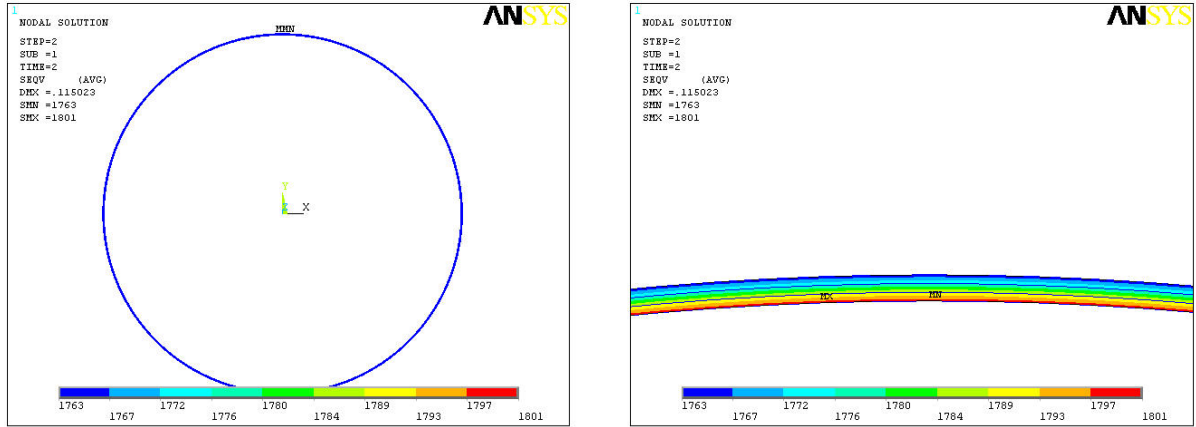
Figure 5-18 Von Misses stress resulting due to inflation pressure on Continuous Single Wire Tire Bead

Von Misses stress resulting on the Continuous Single Wire Bead due to 50 PSI inflation pressure is shown in figure:5-18. Maximum Von Misses stress in the Continuous Single Wire is uniformly distributed all along the inner side of the Continuous Single Wire Bead and decreasing away from the axis.

Therefore from above figures: 5-14 to 5-18 It is concluded Continuous Single Wire Bead is safer than 0037" and 0.051" Weftless Bead.
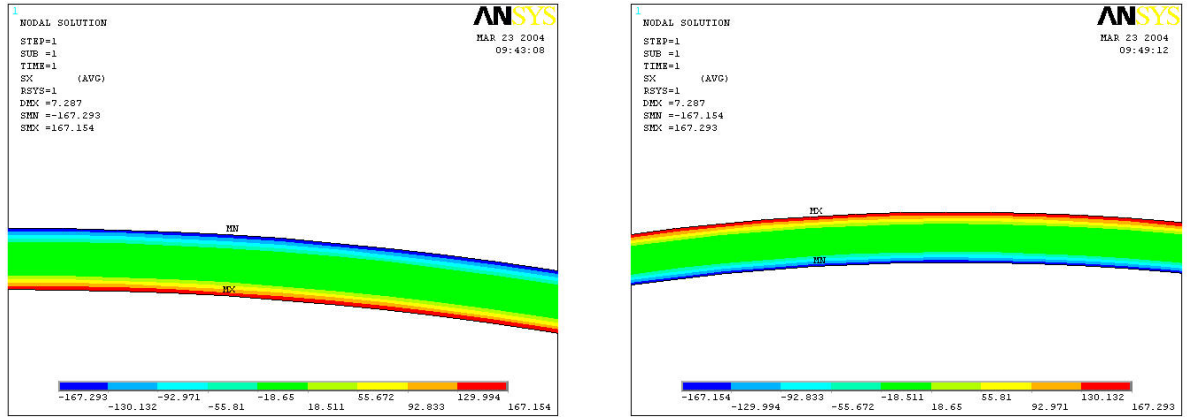
5.4.   BENDING GROUP OF WIRES
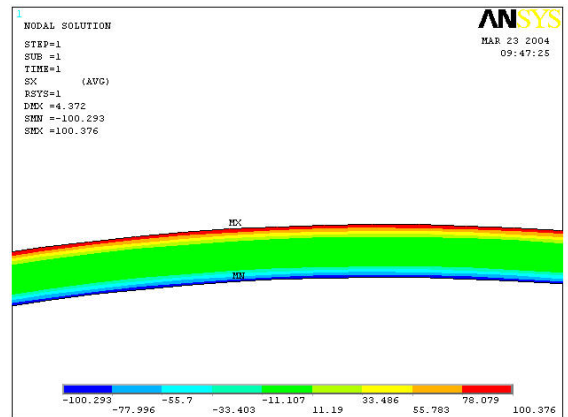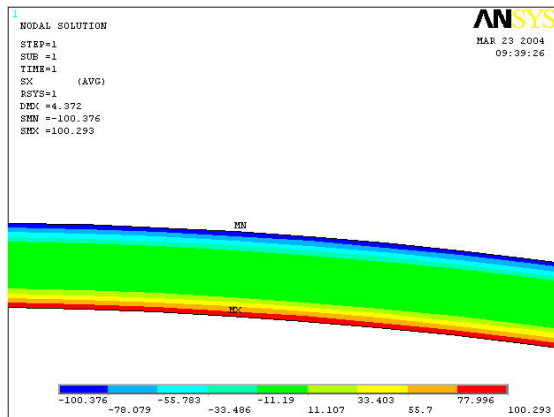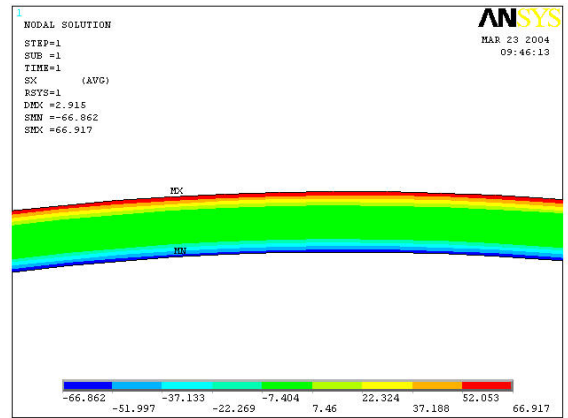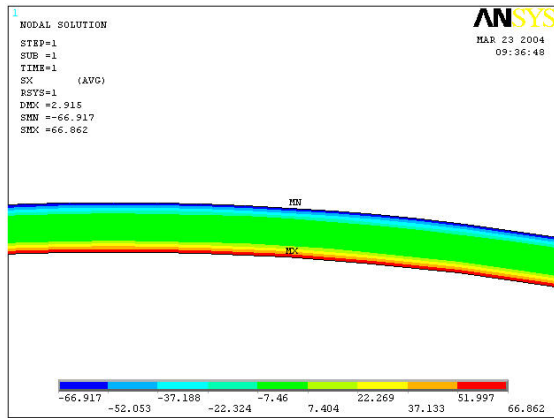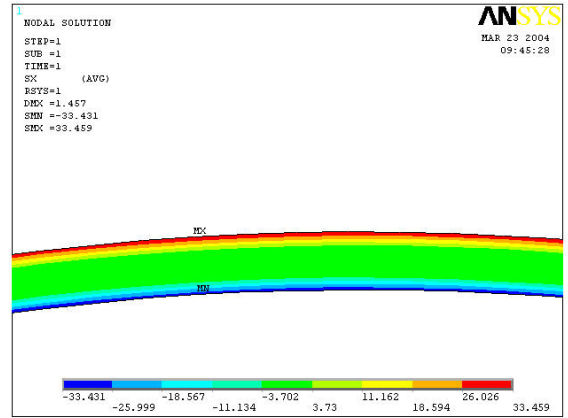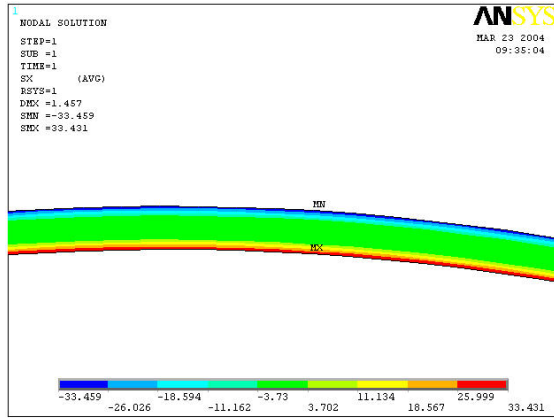
Figure 5-19 Bending Group of Wires

When a simply supported beam is subjected to point load at the center of the beam results in compression on the loaded side and tension on opposite side. Similarly a group of wires bend to larger radius results in outer group of wires subjected to compression and inner group of wires are subjected to tension and when the wires are bend to a smaller radius outer end of the wires are subjected to tension and inner end of the wires are subjected to compression. Tension and compression of the group of wires are shown in figure: 5-19 with blue color representing the compression and red color representing the tension. Therefore the bead grommet bent to a larger radius or smaller radius due to defects during the manufacturing results in bead tension and chances of failure due to mounting.

5.5.0.037" WEFTLESS BEAD BEHAVIOR DUE TO 0.25" RADIAL LOAD

Generally Tire inner diameter is made little bit smaller than the Rim bead seat diameter for a tight fit between the tire and the wheel. A compression fit is required especially between tubeless tire and the wheel to protect the escaping air between tire and wheel gap. Radial loads also occur in the Beads during the mounting of the tire over the rim by button-holing technique.

Therefore in this section beads are analyzed for a 0.25" radial displacement load occurs due to mounting and initial compression of the tire.
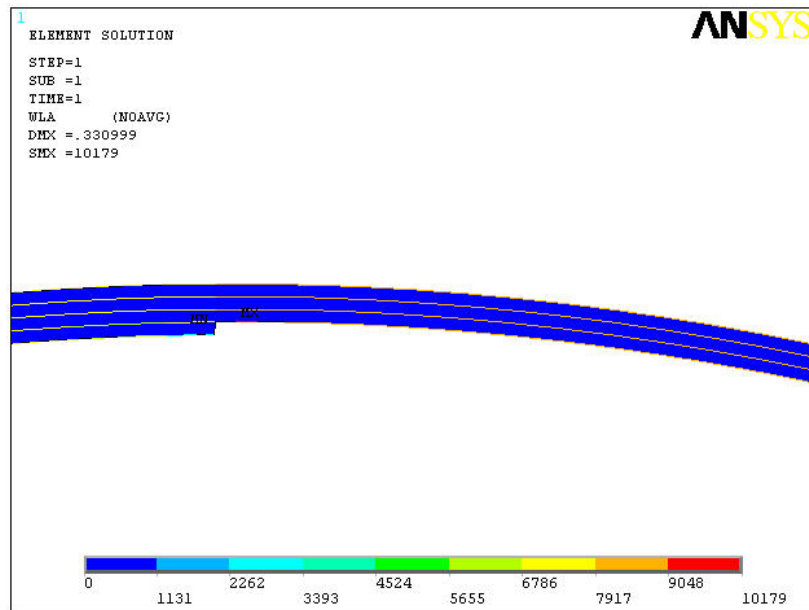
Figure 5-20 Maximum stress in the 0.037" Weftless Bead for 0.25" Radial Load

Figure: 5-20 shows the Maximum stress occurring in the 0.037" Weftless Bead due to 0.25" radial load. Maximum stress occurring is 10179 lb/in^2.
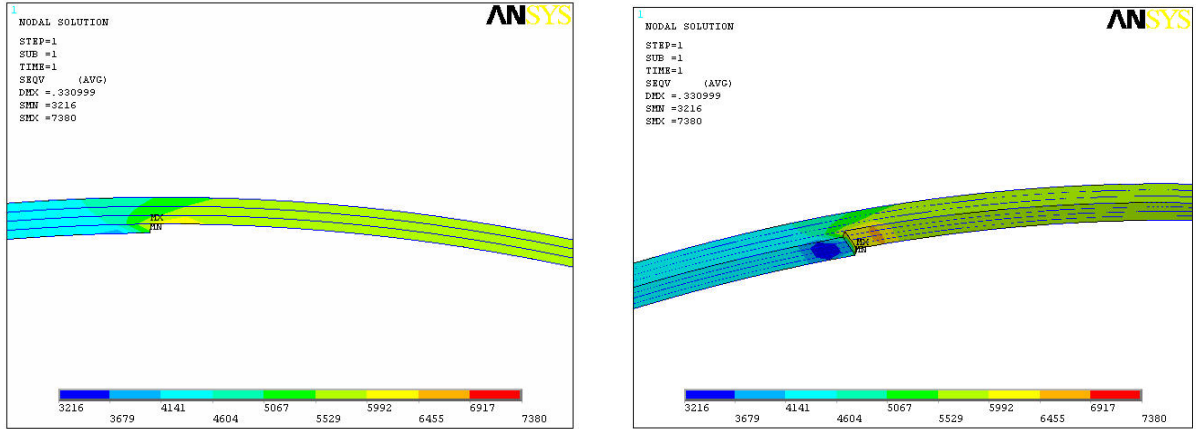
Figure 5-21 Maximum Von Misses Stress in the 0.037" Weftless Bead for 0.25" Radial Load

The maximum Von Misses Stress resulting in the 0.037" Weftless Bead due to 0.25" Compression fit is shown in the figure: 5-20 and it is occurring at the inner end of the splice. Maximum Von Misses Stress occurring due to 0.25" radial load is 7380 higher than the stress occurring due tire inflation pressure.

From fig: 5-20 and fig: 5-21 it can be concluded that the Maximum Von Misses stress is occurring near the splice. Therefore splice is the weakest point and prone to failure for 0.037" weftless bead. When the tire is button holed onto the wheel bead is also being rotated in addition to the bending. These bent and rotated bead gets distorted and separated resulting to tire failure when inflated.

5.6. 0.051 INCH WEFTLESS BEAD BEHAVIOR DUE TO 0.25"
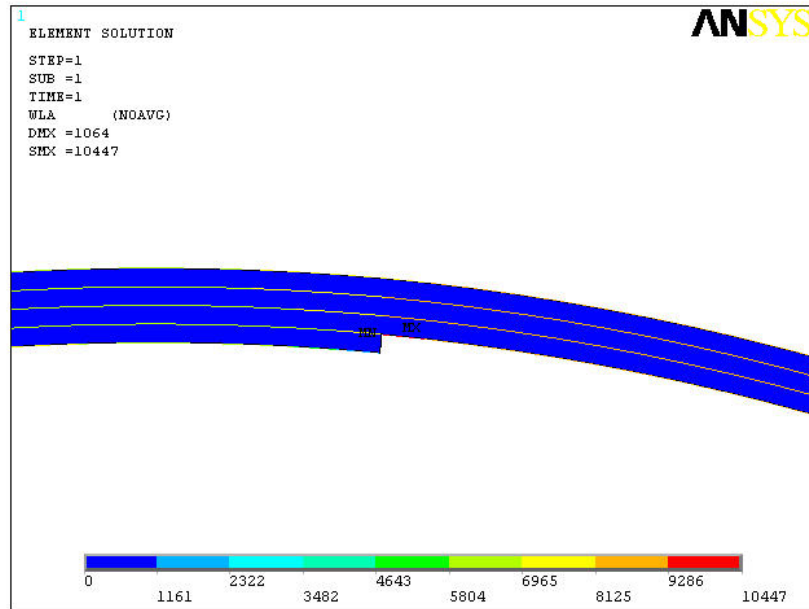## RADIAL LOAD

Figure 5-22 Maximum Stress in the 0.051" Weftless Bead for 0.25" Radial Load

Figure: 5-22 shows the Maximum stress occurring in the 0.051" Weftless bead due to 0.25" radial load. Maximum stress occurring is 10447 lb/in^2.
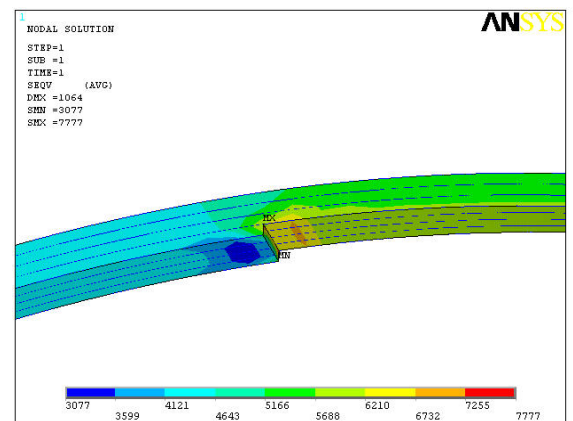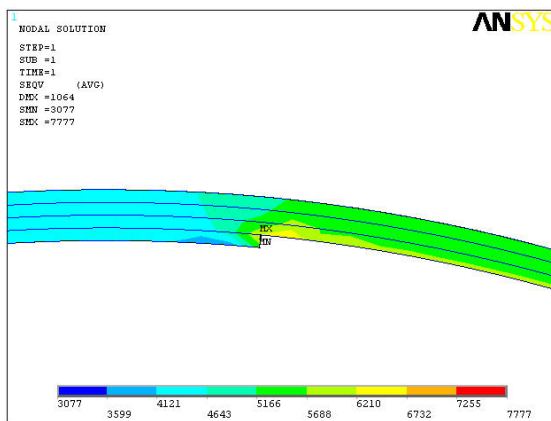

Figure 5-23 Maximum Von Misses Stress in the 0.051" Weftless Bead for 0.25" Radial Load

Strength of the bead wire is proportional to the square of the diameter of the bead wire. As the diameter of the bead wire is increased from 0.037" to 0.051" Strength of the bead wire is increased by 180%. Therefore the allowable stress in the 0.051" weftless bead is 12600 (7000x1.8). Maximum Von Misses Stress occurring in the 0.051' weftless bead due to 0.25" radial load is 7777 less than the allowable stress.

Maximum Von Misses stress occurring in the 0.051" Weftless bead is near the start of the under lap of the weftless bead. Therefore splice in the weftless bead is always the weakest point during mounting.

5.7. 0.037" CONTINUOUS BEAD BEHAVIOUR DUE TO 0.25" RADIAL LOAD
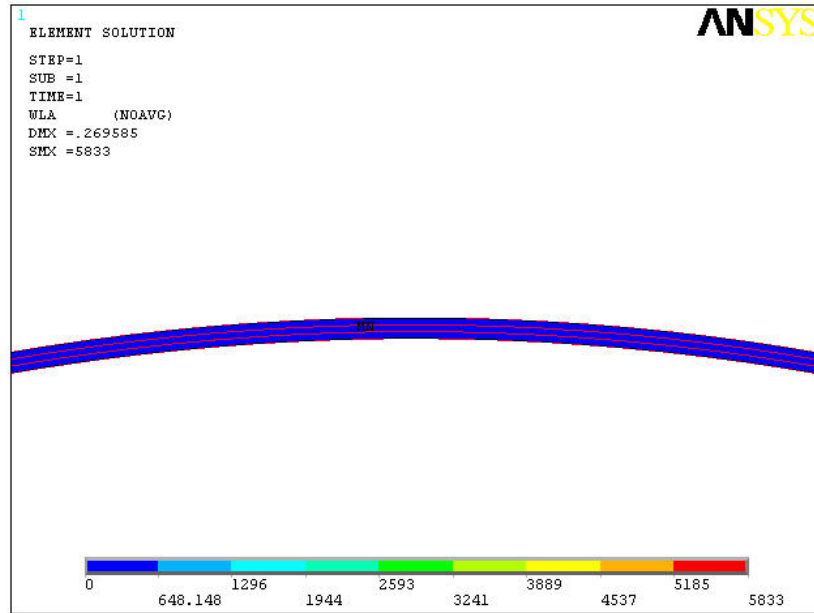

Figure 5-24 Maximum Stress in the Continuous Single Wire Bead due to 0.25" Radial Load
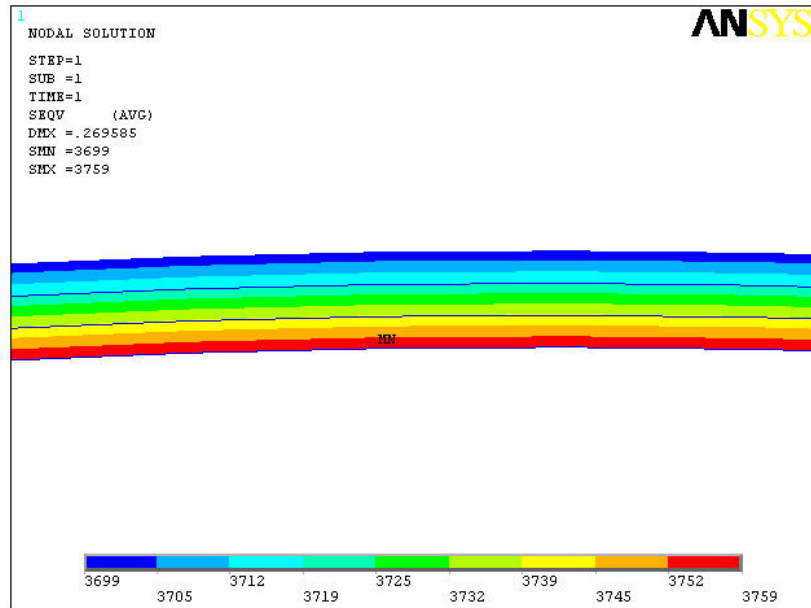

Figure 5-25 Maximum Von Misses in the Continuous Single Wire Bead due to 0.25" Radial Load

Figure: 5-24, shows the Maximum Stress occurring in the Continuous Single wire tire Bead due to 0.25" radial load. Maximum stress occurring in Continuous Single Wire bead is 5833.

Maximum Von Misses stress occurring in the Continuous Single Wire Bead from figure: 5-25 is 3759 which is less than the allowable maximum stress. Continuous Single wire bead has a uniform flexural rigidity with two wire cut ends instead of ten wire cut ends as of weftless bead eliminating the problem during mounting.

5.8. WEFTLESS BEAD HANGUP OVER" WHEEL

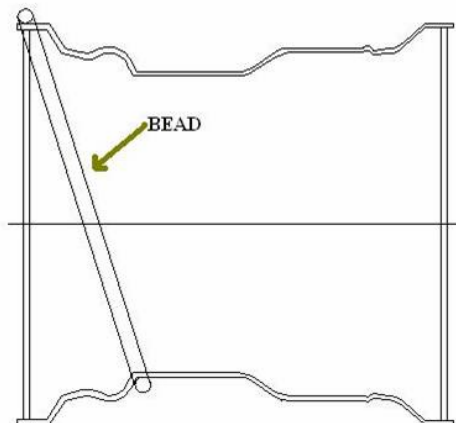When the tire is being mounted on a wheel, the bead is elongated as shown in the figure: 5-26 shown below.
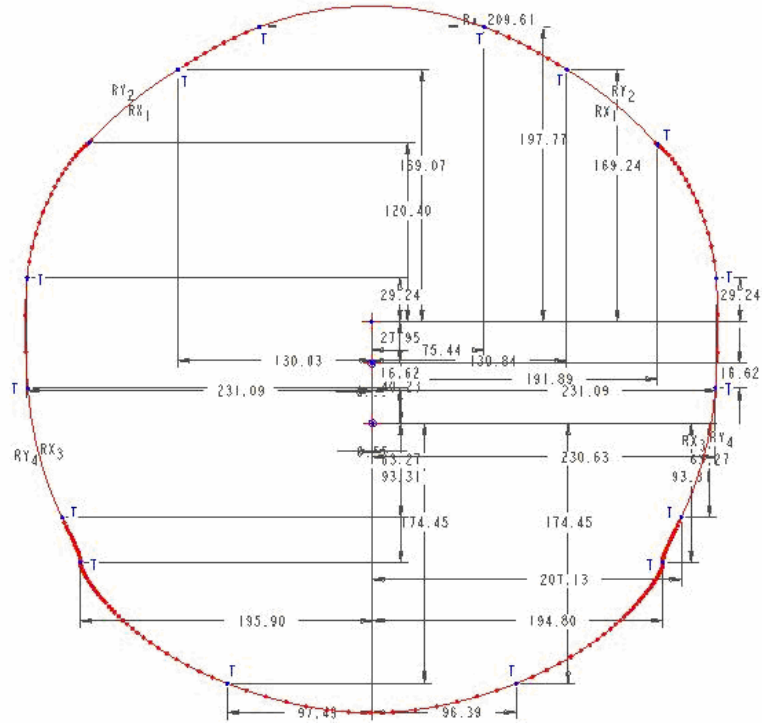

Figure 5-26 Bead Mounting

Figure 5-27 Bead Profile over the Wheel

Figure 5-27 is the resulting profile when the bead positioned over the wheel as in figure 5-26. From figure 5-27 it is deducted that the bead is being bend to varying radiuses during mounting. If the bead is bend to a higher radius the inner ribbon is being under tension and outer ribbon is being under compression, similarly if the bead is bend to smaller radius the outer ribbon is being tensioned and the inner ribbon is being compressed. When the tire with weftless bead is being mounted on the wheel and if the splice is the last portion to move over the wheel hump when inflated results in bead rotation and bent to higher radius causing weftless ribbon to separate and get distorted .

Therefore splice is the weakest point in 0.037" weftless bead and more prone to failure than 0.051" weftless which can accept more stresses than 0.037" weftless bead.
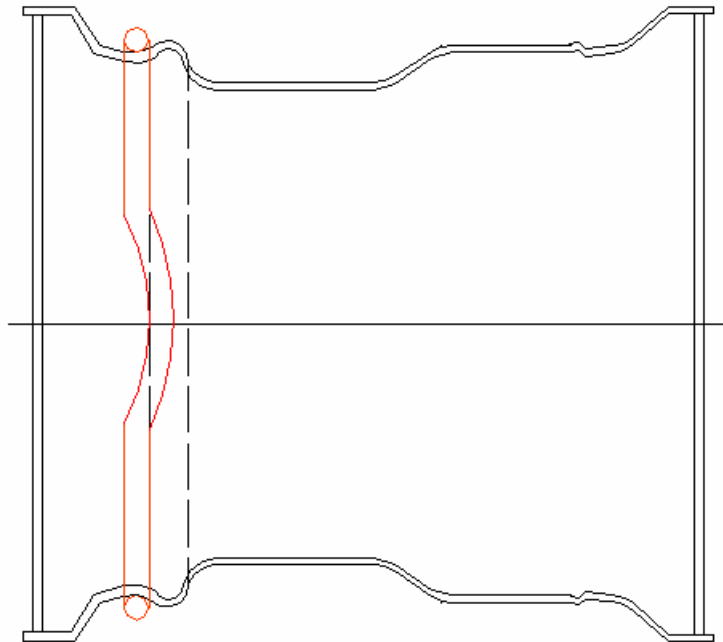
Figure 5-28 Bead Hang-up

Figure: 5-28 shows the hang-up bead on the wheel and becomes unstabilized. If by chance the unstabilized location happens to be in the area of the slice at the inside cut edge of the five wires where the bead bundle begins, the tensile strength of the wire carrying the full load of the inflation pressure is exceed and it fails. This unstabilization results in grommet separate into a configuration and where not all the wires in the bead bundle are carrying an equal load, The wires forming grommet becomes separated and only one wire end up carrying the full inflation load and breaks . At the instant when the first wire breaks, the load is immediately transferred to the next wire which breaks and in rapid succession all of the wires in the bead bundle rupture.

5.9. VARIATION OF STRESS VERSUS TIRE BEAD RADIUS:

The following graph shows the variation of stress Vs the radius of the bead. Increasing the radius the tire bead increases the stresses in the bead wire. Therefore larger the diameter of the tire larger the diameter of tire bead which linearly increases the stresses in tire bead.

5.10.   TOLERANCE OF THE TIRE BEAD:

Diameter of the tire bead is critical to the functioning of the tire bead. A larger bead tolerance limits in the dimensions of the tire beads results in less reliable tires than a tire with more tight tolerances during manufacturing. A positive tolerance over nominal diameter of the tire bead results in higher stress due to compression and negative tolerance over nominal diameter of the tire bead results in higher stresses due to compression.
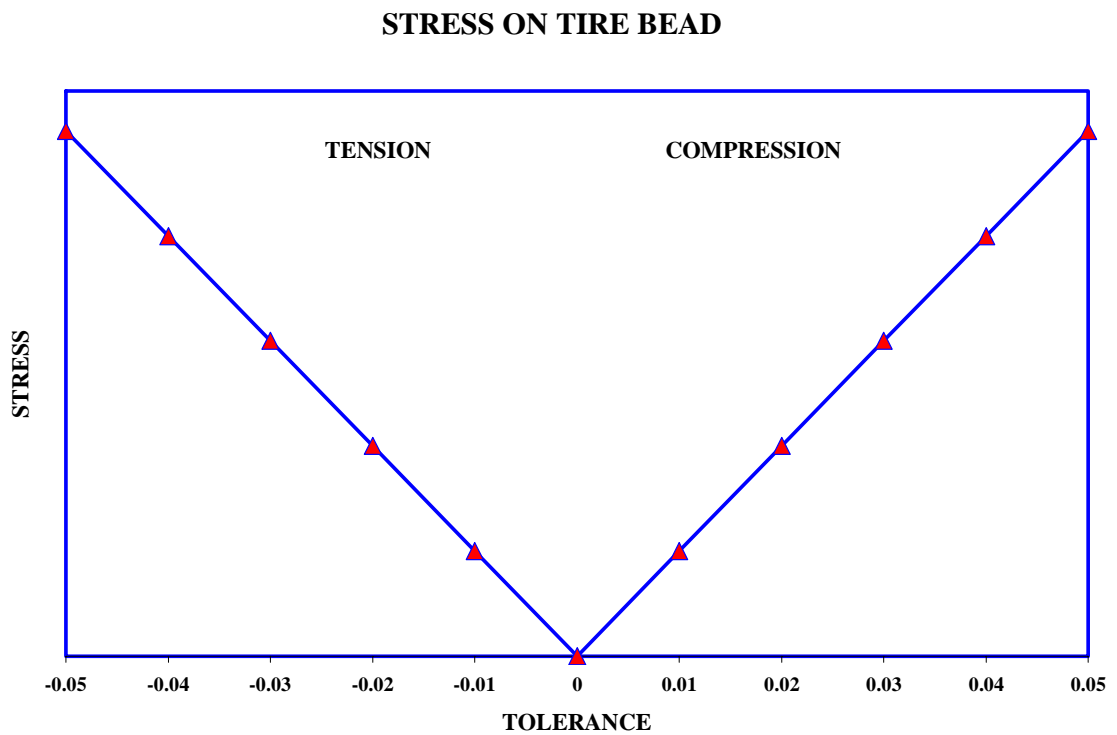
STRESS ON TIRE BEAD

Figure 5-29 Tolerance of the Tire bead

Therefore bead manufactured smaller than the mean critical diameter results in tension and causing failure and a bead made larger diameter than the critical results in bead kinking while mounted and causing failure.

6. CONCLUSIONS

- Finite element model developed in this thesis for the Weftless bead and Continuous single wire bead has the advantage of more detailed finite element analysis of the failure phenomenon of 0.037" weftless Bead

- 0.037" Weftless Bead can hold the air tire pressure provided bead is properly seated on to the bead well. Distortion in the bead grommet area generally occurs if the splice is the last portion of the bead to seat. This results in distortion of the bead wire and grommet gets separated resulting in one wire end up carrying full inflation pressure. Therefore, if ever weftless bead is to be used, splice area should be marked. It is important that while mounting the tire with marked splice region of the weftless bead should be button holed without any distortion and rotation of the bead

- The failure point of 0.037" Weftless is always the underlap or starting point of the grommet with ten wire cut ends, five in the inner side and five on the outer end. Continuous Single wire bead has two cut ends one in the inner end and one in the outer lap eliminating weaker splice region.

- Distortion near the end of the splice region can also be eliminated by tying or stapling the splice end of the underlap of the grommet.

- Flexural rigidity throughout the bead should be maintained constant in order to protect the bead from high stress concentration near splice region while mounting. Weftless bead which has a sharp change due to five cut wire ends results in high stress concentration resulting in higher tensile forces resulting in failure near the underlap of the weftless bead. Continuous Single bead wire which has single wire cut ends on both ends of the grommet has a consistent flexural rigidity without any high stress concentration.

- Increasing the bead wire diameter to 0.051" results in increases strength of bead wire near the weak splice area by 80% eliminating the weak splice region.

- Beads should be manufactured to within the tolerance limits without any defects. Bead smaller than the specified tolerance results in higher tension on the inner side and compression on the outer side and a bead made larger than the tolerance results in bead kinking.

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