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*Phil. Trans. R. Soc. Lond. A* 1980 **294**, 577-582
doi: 10.1098/rsta.1980.0067

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*Phil. Trans. R. Soc. Lond.* A **294**, 577–582 (1980)
*Printed in Great Britain*



# Automotive drive shafts

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One part of the work of composite engineers is to find cost effective uses for new fibre composites. One such use identified for carbon fibre is in the automotive propeller shaft. This is the fore and aft shaft transmitting the engine torque of a car or truck to the driven axle to propel the vehicle.

This paper will relate the requirements for drive shafts to the properties of carbon fibres. Both technical and marketing requirements will be considered. The carbon fibre properties are related to performance when incorporated in a resin matrix.

Reference will be made to work on 'alloying' carbon fibre with glass fibre. This is shown to enhance the overall cost effectiveness of the resulting parts.

A final section will illustrate the important aspect of producing test data that build up the automotive designer's confidence in the application of an unfamiliar material.

## Introduction

This paper describes one use found for new fibres in a resin matrix – that of automotive drive shafts. The reasons for the choice of composites in this application, and the work necessary to demonstrate that the application is sound and cost effective, are outlined in the following sections.

## 1. Choice of application

Composite applications are a matter of cost effectiveness. Cost has, these days, to be considered at every stage of launching a new application. Unless the user can be shown reasons, in money terms, for using a new product, it is most unlikely that the product will reach the market place.

The British reticence to bring cost into scientific and technical papers and discussions could well be one reason why British ideas and inventions seem often to be more successfully exploited overseas than at home. In this case the application is in a market where mass saving is recognized to have an economic value. The magnitude of this value will range between applications and country of eventual use, but can easily reach £2.2/kg of mass saved.

In this particular application the use of carbon fibre has a compounding effect in that the very efficiency of carbon fibre enables the component design to be simplified, thus further reducing cost and mass. This simplification in turn improves performance aspects, as will be described in a later section. Thus we have the dual reason so often necessary to introduce composites into a new application.

## 2. Component and function

Figure 1 shows a composite drive shaft being fitted to a car. The shaft transmits the engine torque from the rear of the gearbox to the rear driven axle of the vehicle. Typical requirements involved for a two litre car are:



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(i) a torque loading of 1130 N m;
(ii) a maximum rotational speed of 5500 rev/min;
(iii) a length of 1 m;
(iv) an allowable diameter of 76 mm;
(v) a temperature range of $-40$ °C to $+120$ °C.

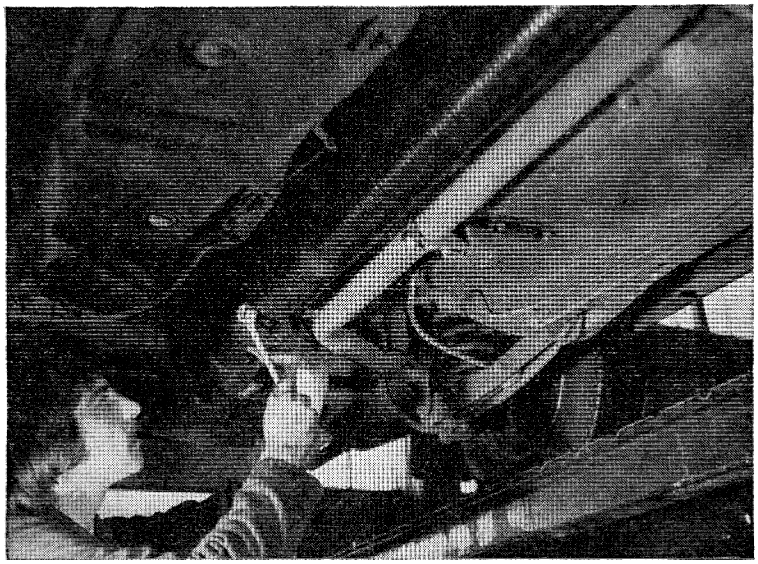

FIGURE 1. A composite drive shaft being fitted to a car.

## 3. Design factors

Marketing considerations are paramount in the motor car industry. Two factors make this particular application attractive to the industry at this time. On the one hand, vehicles are sold in the market place on claims of increased comfort, luxury and smoothness of operation. On the other hand, the manufacturer is also seeking to provide the maximum performance with the minimum fuel usage. Usually these two requirements are conflicting. For example, a decrease in body panel thickness reduces mass and so increases performance and fuel efficiency, but this change also increases internal noise. The use of carbon fibre in drive shafts contributes to achieving both aims simultaneously.

The factors to be optimized in a shaft after meeting the basic operating requirements just outlined are mass, smoothness of ride, and cost. Reducing mass is important:

(1) to improve performance of the vehicle and to reduce fuel consumption,
(2) to reduce unsprung mass, and so improve vehicle handling and ride, and
(3) to reduce the residual out-of-balance forces from rotating parts and so further improve smoothness in use.

A carbon fibre composite drive shaft is about half the mass of a steel unit for the same operation, typically weighing 4.5 kg instead of 9 kg.

The motor industry refers to smoothness of operation as reduction in n.v.h., where these letters stand for noise, vibration and harshness. It is an area where art, flair and design acumen often appear to have an edge over scientific measurement. However, figure 2 shows two simple



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traces generated on a car running first with a conventional steel propeller and then with a carbon fibre composite alternative. In each case the vehicle was accelerated from rest to a maximum speed, then the clutch was disengaged and the vehicle brought to rest by the application of brakes. The noise level in the passenger compartment in each case is shown with a clear reduction in the case of the composite shaft.

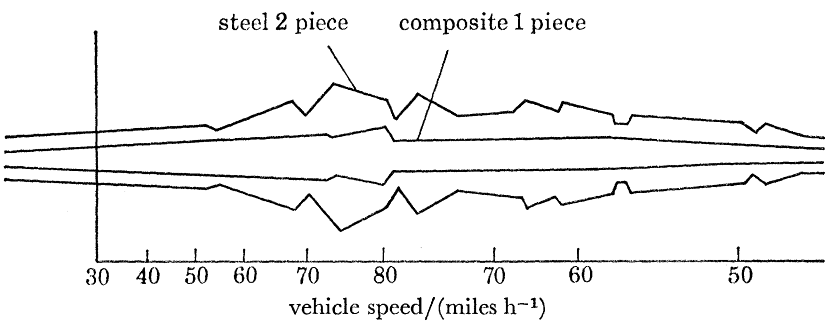


FIGURE 2. Internal noise levels. Comparison of steel and composite drive shafts, on the same vehicle.

Turning to the vital matter of cost, carbon fibre at the present time is expensive even in quantity, costing some £31/kg as compared with steel tube at perhaps £0.90/kg.

Figure 3 compares material prices on a log scale against time. Sheet steel prices show a steady rise linked to current inflation rates. The curve for epoxy resin, the likely binder for carbon and

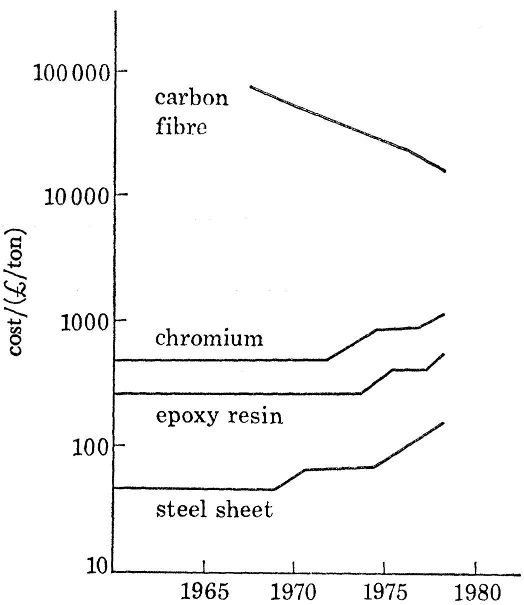


FIGURE 3. Material prices.

glass fibre in drive shafts, shows a similar trend. Glass rovings also follow a similar pattern although omitted from the illustration for the sake of clarity. The curve for chromium is included to illustrate the fact that relatively expensive alloying materials are already included in automotive parts; the use of carbon fibre may be put in a similar category in composite drive shafts.

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Finally, the curve for carbon fibre shows the dramatic drop in the cost of this material since its introduction. This reduction largely follows the increase in usage of the material and consequent economies of production, and the trend should continue for several years as the automotive and other users continue to increase the volume required.

## 4. Design of a composite shaft

Figure 4 shows two typical shafts side by side, one made in steel and the other in composites. The illustration shows the simplicity of the design made possible by carbon fibre.

The combination of high stiffness and low density in the composite enables a longer shaft to be made without reaching a critical whirling speed. The whirling speed of a rotating shaft is the speed at which it becomes unstable and deflexions occur normal to the axis of rotation. The advantage in whirling speed is such as to enable most two-piece steel shafts to be replaced with a single composite part.

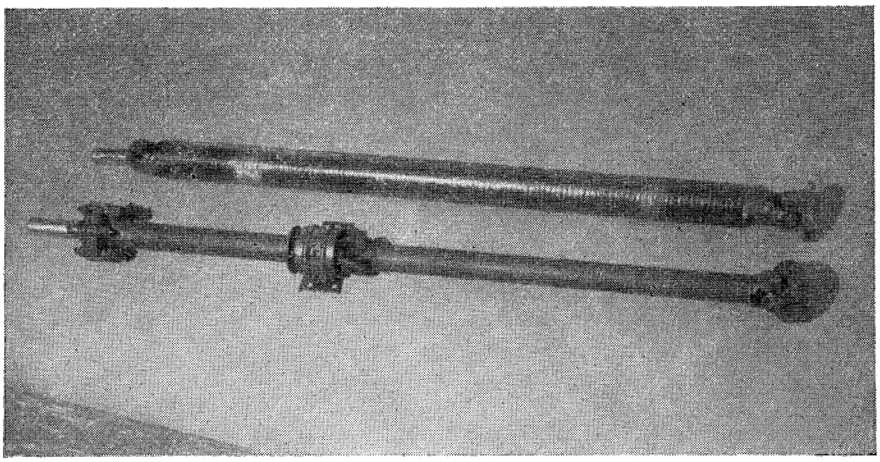

Figure 4. Composite drive shaft (upper) with corresponding steel shaft.

Weight and cost are reduced by dispensing with the central universal joint and the associated bearing. N.v.h. factors are improved by the consequent isolation of the passenger compartment from drive line vibration following deletion of the centre bearing from underneath the driver's seat. Further reductions in n.v.h. are possible by modification to the orientations of the fibres in the propeller shaft tube, which effect longitudinal and radial stiffness.

Figure 5 illustrates manufacture of a composite tube – in this case with glass fibre – showing how the fibres are unwound from spools, impregnated with a laminating resin, and then wound onto a mandrel in a helical pattern.

For a drive shaft the angles at which the fibres are laid has been the subject of some evolution. Initial shafts were optimized around the torsion requirements with the carbon fibre set near to the angle required for best torque capacity. Carbon fibres carried both torque and whirling loads. These shafts were adequate in torque capacity and in resisting whirling, but far too expensive to compete with metal shafts.

A second stage of work was characterized by the separation of the fibres carrying torque loads for which glass fibre was found adequate, from those imparting whirling resistance for which carbon fibre proved ideal. Where two types of fibre are used in a single structure, the



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construction is referred to as a hybrid. In this case the mix of fibre reduces unit cost at a small mass penalty. This results in a considerable improvement in cost effectiveness.

In a third refinement additional fibre hoop winds may be added to prevent cross section distortions under load.

By so minimizing both the amount of carbon fibre required, and the parts count, i.e. omitting the centre universal joint and bearing, the design has reached a stage of cost effectiveness and a first cost not substantially greater than that of the existing part.

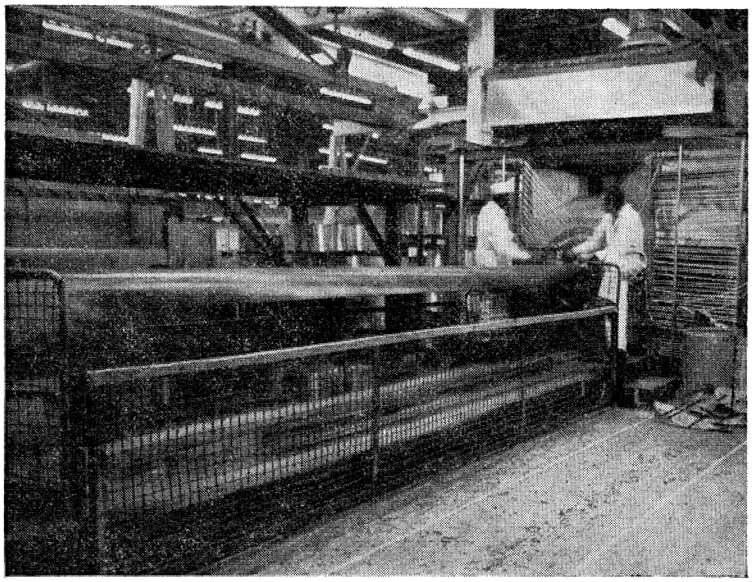

FIGURE 5. Manufacture of composite tube.

## 5. Proving tests

After the obvious laboratory tests to show static strength and stiffness, fatigue tests are important. Carbon fibre has an excellent performance in fatigue, and glass fibre is as good as most metals. A composite shaft has withstood $10^6$ cycles of maximum torque as compared with the $10^4$ cycles typically required of a steel shaft.

Shafts were fitted to cars to gain road experience and demonstrate satisfactory operations. Such testing demonstrates that the component really works and meets all the criteria required, not only those specified on paper. In this application, for instance, road use showed that:

(1) temperature resistance to underbody environment was satisfactory;
(2) corrosion resistance, e.g. to salt spray, was not a problem;
(3) creep loading resistance was adequate;
(4) resistance to flying stone damage was not a problem;
(5) end attachment strength was adequate;
(6) shock load capability was adequate.

All these points were satisfactorily demonstrated on a Company fleet car which has now completed some 105000 km, running over three years and which, with extensive engine rebuilding, will be taken to 160000 km.



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Composite shafts have now been successfully run on some dozen different vehicles, and over 240000 km accumulated. Commercial exploitation of this work is in hand through our partner in the G.K.N. Automotive Group, the B.R.D. Company.

## 6. Conclusion

In addition to surveying briefly an application of carbon fibre of great significance, it is hoped this paper has shown something of the role of the engineer in bringing new materials to the market place.

However good a new fibre may be, engineers are still needed to find cost effective applications and then bring these applications to fruitful use.

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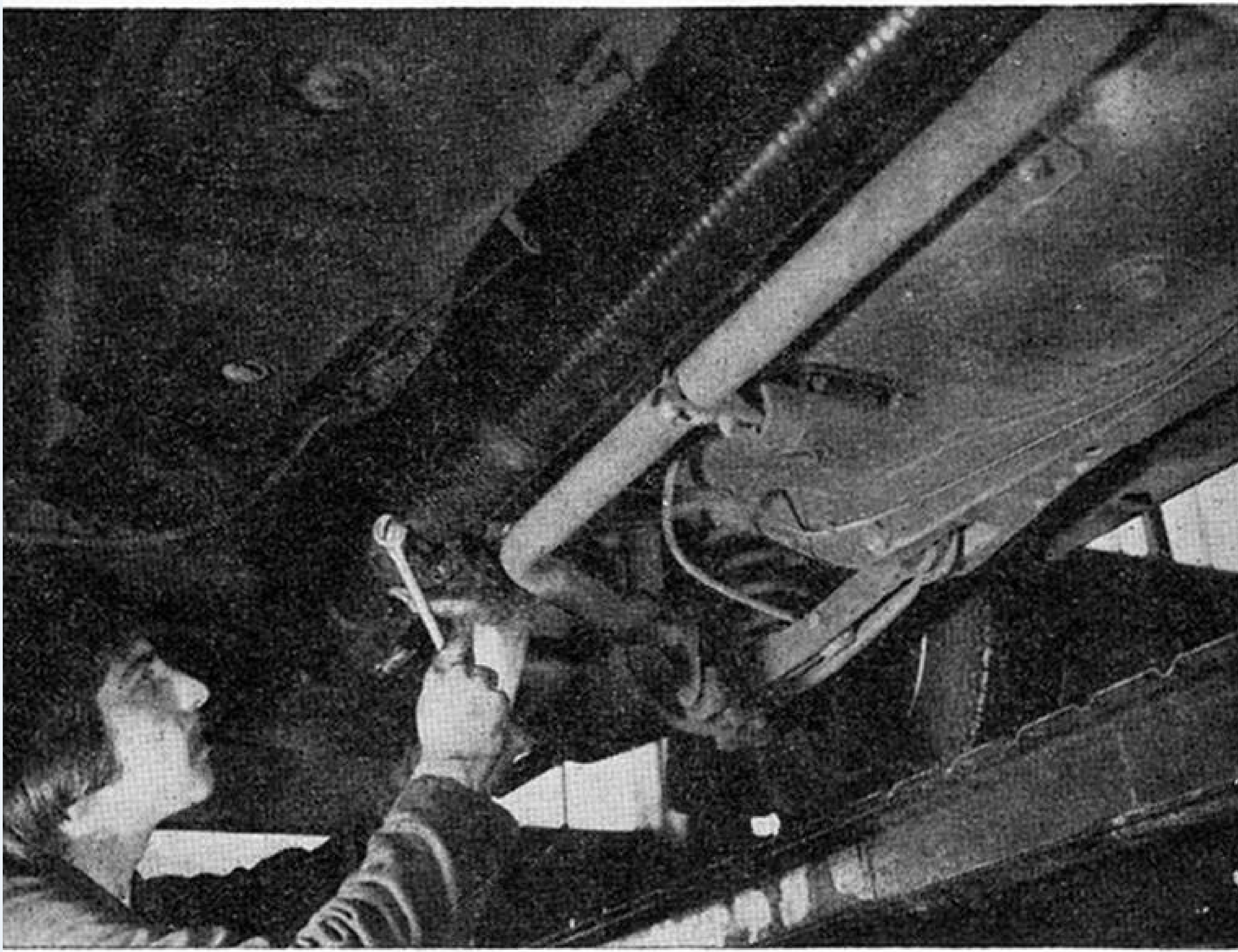

FIGURE 1. A composite drive shaft being fitted to a car.

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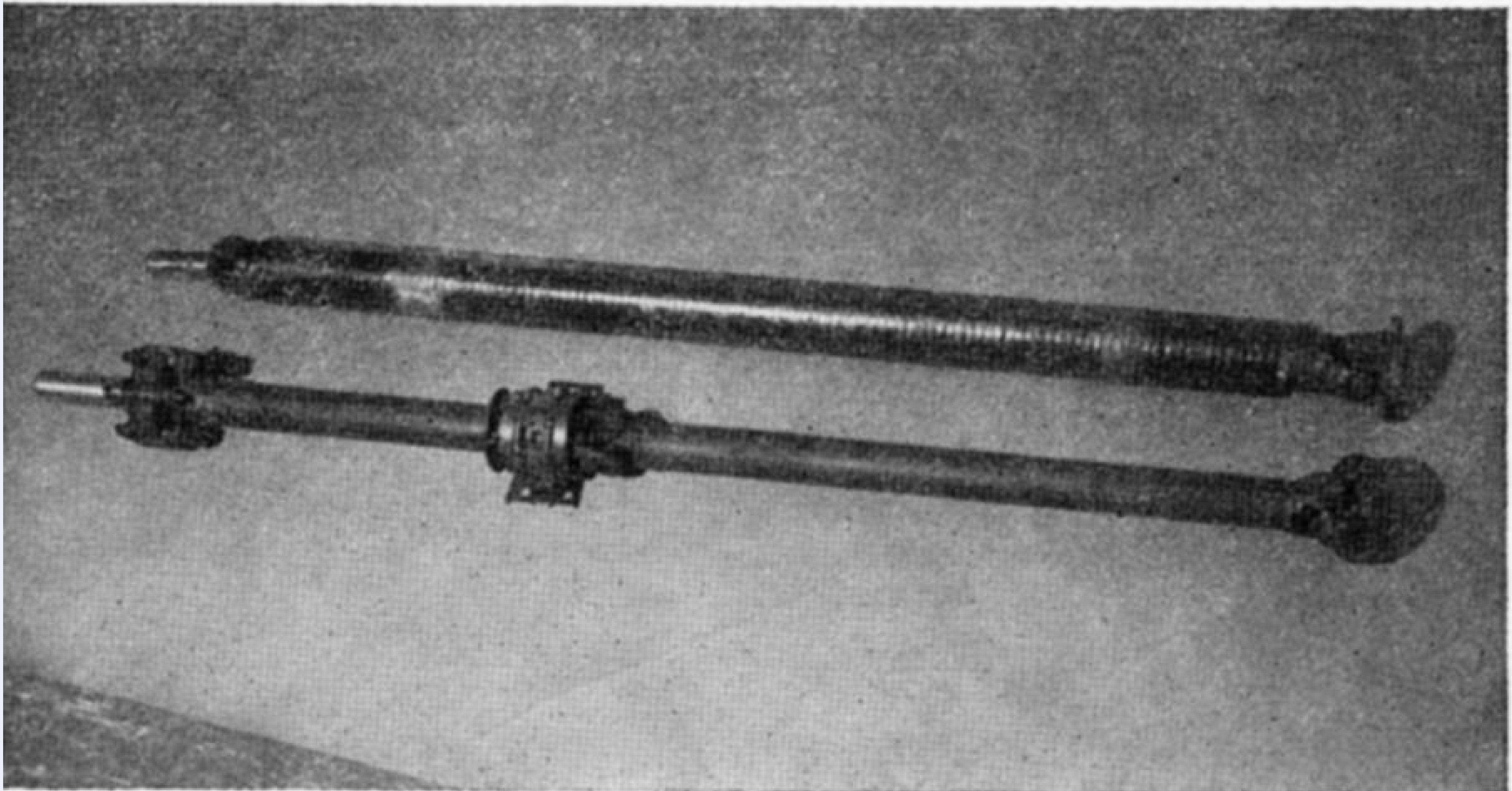

FIGURE 4. Composite drive shaft (upper) with corresponding steel shaft.

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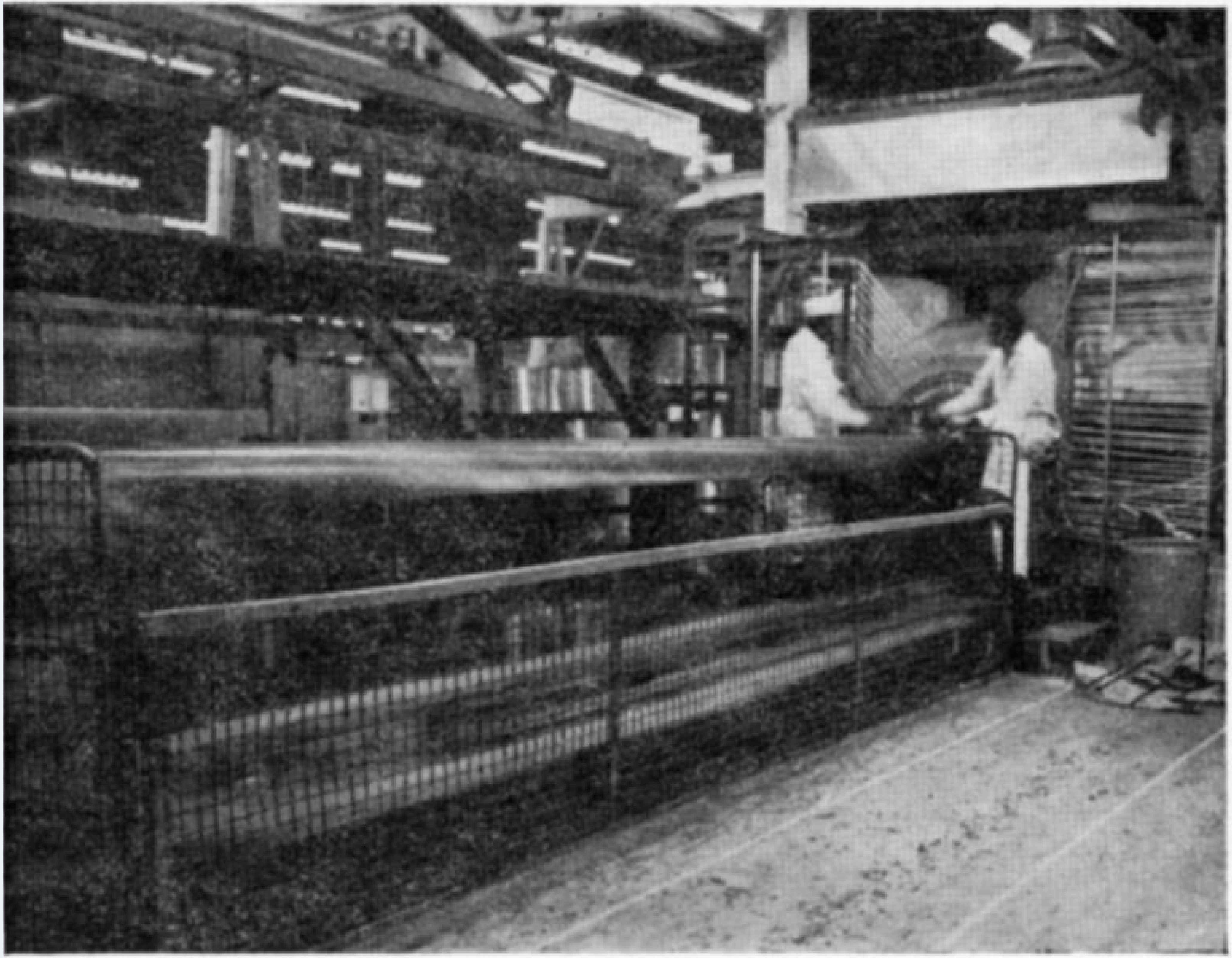

FIGURE 5. Manufacture of composite tube.