TECHNICAL NOTE
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Forest Research
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TECHNICAL DEVELOPMENT BRANCH

WOODFUEL CHIPPING: FIELD TRIALS

Summary

Examples of the 3 main chipper types commonly available (Disc, Drum and Screwcone Chunker) were tested and factors that might affect output and the quality of the chips produced examined. The main factors identified were:

- Feed material length and diameter.
- Feed material moisture content and density.
- Machine set up characteristics.

A variety of feedstock material was processed and outputs were dependent on machine power rather than the maximum size capability.

Based on the Danish Industry Chip Classification:

- Coarse chips were produced by all machines from all feedstock.
- Fine chips were produced from all feedstock by some machines.
- Fine chips could not be produced by some machines from some feedstock.

Problems identified with dust inhalation and noise highlighted the need for further investigation.

Introduction

In recent years a number of projects concerned with the production of wood chip, have been commissioned by the Forestry Commission and ETSU. These have examined various comminution machines working on a variety of materials ranging through short rotation coppice, short and pole length wood and harvesting residues. The resultant chipped product can be used in a variety of ways including mulch, a horse riding surface, and as a fuel.

Small scale wood burners, capable of using woodchips, are available. However, the quality of chip can be variable and many of the burners have a tight

Plate 1

Greenmech Disc Chipper

specification as to the optimum and maximum chip sizes they can use. The predominant problem is that of material too large to pass through the feed hopper or screw feed, blocking the feed mechanism.

Technical Development Branch (TDB) was commissioned by the Forestry Commission and part funded by British Biogen to examine these problems and complement and further expand knowledge on the range of comminution machines available and the quality of material produced.

Health and safety issues and safe working practice were also examined.

Machine Choice

The 6 machines chosen for trial represented the range of models available on the market. Details of the machines chosen are in Table 1.

Disc Chippers: This type of machine is the most readily available type of chipper found in the UK. It consists of a heavy flywheel with varying numbers of radially set blades cutting against an anvil. The machines chosen for test all had fully reversible, hydraulically powered feed rollers. The feed rollers on the Greenmech (Plate 1) and Gandini (Plate 2) machines could be set at a range of speeds and both units incorporated a 'no stress' feed control system.

When the revolutions on the flywheel drop below a certain set level during processing, the feed rollers stop, allowing the flywheel to regain its momentum and the feed rollers to restart. The feed rollers of the Gravely (Plate 3) are manually controlled with the stop/start/reverse bar.

Plate 2

Gandini Disc Chipper

Plate 3

Gravely Disc Chipper

The Greenmech model was supplied with unique disc chip blades (Plate 4). These are circular cutting blades mounted in sets of three as opposed to the usual single blade.

Plate 4

Greenmech Disc Chip Blades

Screwcone Chunker: The Sasmo (Plate 5) represents the screwcone chunker style of chipper. The combined feed and cutting mechanism is a horizontally mounted spiral blade (Plate 6). Material is drawn into the feed chute by the action of the blade. Longer material can be fed by a grapple which is used to restrain the material and prevent stalling of the tractor unit. During manual feeding the hand actuated 'feed cut off' mechanism is used. Large diameter shortwood may need to be cut into shorter pieces, to prevent stalling. In the trial the SS blade (smallest available) was used which is designed to produce chips in the 15 mm to 25 mm range.

Plate 5

Sasmo Screwcone Chunker

Table 1

Machine Types and General Details

Item	Sasmo HP 25	Gravely 395 Pro Chip	Greenmech MT 252	Gandini 007 TPS	Morbark EZ Beaver 10	Jenz HE300 670STA
Machine Type	Cone Screw Wood Chunker	Disc	Disc	Disc	Drum	Drum
Power	PTO Driven 540 to 1000 rpm Hand fed 80 to 130 hp Grapple 90 to 160 hp	Yanmar Diesel 41.5 hp @ 3 000 rpm	Lister Diesel 55 hp @ 3 000 rpm	PTO Driven 66 to 110 hp	Perkins Diesel 80 hp @ 2 500 rpm	Volvo Diesel 189 hp
Weight (Kg)	1670	1250	1800	1000	1360	4500
Cutting System	SS screw blade	2 blades on fly wheel	3 x 3 discs on fly wheel	3 double sided blades on fly wheel	1 x blade on drum	14 blades in 2 staggered rows
Max Feed Size (mm)	250	240	250	270	250	355
Discharge Height (mm)	3200	2100	2720	3450	2210	Conveyor to suit
Feed Rollers	None	2 weight tensioned fixed speed	2 variable speed. Top roller raised by hydraulics	2 variable speed. Top roller raised by hydraulics	1 weighted top feed roller. Raised by hydraulics	2 Feed rollers Top roller hydraulically raised
Feed Control	None specifically, but a feed cut-off is fitted.	Manual control using stop/reverse bar	'No stress' system automatic feed control	'No stress' system automatic feed control	'No stress' system automatic feed control	'No stress' system automatic feed control
Manufacturers Agents	Fuelwood Harvesting, Claywood, Beausale, Warks. CV35 7NX Tel. 01926 484673	Westcon Equip Ltd, Unit 2A, 27 Brook Rd, Wimborne, Dorset. BH21 2BH Tel. 01202 880380	Greenmech Ltd, Mill Industrial Park, Kings Coughton, Alcester ,Warks. B49 5QG Tel. 01789 400044	Chippers International Ltd, Little Acres Farm, Kings Lane, Snitterfield, Warks. CV37 0QZ. Tel. 01789 414871	Stewart Lumber, Block 6, Unit 4, Lomond Industrial Estate, Alexandria, Scotland. G83 0TL Tel. 01389 751154	Woodtec Machinery, Unit 7, New Mills Ind Estate, Inkpen, Hungerford, Berks. RG17 9PU Tel. 01488 668707
1998 Capital Cost (£)	14 000	14 950	19 300	13 600	14 000	58 000

Drum Chipper: The Morbark chipper (Plate 7) has a horizontally mounted drum with a single blade. The material is fed into the machine via fully reversible, variable speed, hydraulically powered feed rollers. A no stress system is also incorporated.

The Jenz is a static drum chipper in use on a private estate supplying chips for a woodfuel heating system. It has an in-built grading plate, which prevents material over a certain size passing to the stockpile and recirculates it back into the drum. Material to be chipped is fed mechanically onto a conveyor from a bench after loading by a forwarder. The operator adjusts material on the conveyor as necessary.

Machine Costs

The purchase price for all chippers (1998) was obtained from respective agents. An hourly charge, for both high and low annual usage, was calculated using a standard procedure (Table 2). The 2 usage rates represent a dedicated woodfuel supplier (high) and a more general contractor or 'self supplier' (low).

A number of assumptions have to be made in the costing procedure. Although different machines are likely to have different life expectancies. Following discussions with the manufacturers a life of 5 000 hrs was generally agreed as a fair estimate for all machines. It was also decided to cost machines over 3 years for high usage and 10 years for low usage.

A cost of £5.00/hr is added to the Sasmo and Gandini for tractor hire. An additional £1.50/hr has to be added to the Sasmo when the loader is used, i.e. when feeding poles.

Table 2

Machine Cost Assumptions

Cost Element	Sasmo HP25		Gravely Pro-Chip 395		Greenmech MT 252 (disc)		Gandini 007 TPS		Morbark EZ Beaver 10		Jenz HE300 670STA	
Capital cost (£) C	14 000		14 950		19 300		13 600		14 000		58 000	
Residual value (£) RV	1400		1495		1930		1360		1400		5800	
Life in hours L	5000		5000		5000		5000		5000		5000	
Machine usage	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Productive hrs/yr PH	500	1667	500	1667	500	1667	500	1667	500	1667	500	1667
Life in years n	10	3	10	3	10	3	10	3	10	3	10	3
Interest % R $(r = \frac{R}{100})$	6	6	6	6	6	6	6	6	6	6	6	6
Discount factor $Dn = \frac{1}{(1+r)^n}$	0.5584	0.8396	0.5584	0.8396	0.5584	0.8396	0.5584	0.8396	0.5584	0.8396	0.5584	0.8396
Equivalent annual cost $An = \frac{1}{1 - Dn}$	0.1359	0.374	0.1359	0.374	0.1359	0.3740	0.1359	0.374	0.1359	0.374	0.1359	0.374
Machine cost (£/hr) $= \frac{[C-(RV \times Dn)]An}{PH}$	3.59	2.88	3.84	3.07	4.95	3.97	3.49	2.8	3.59	2.88	14.88	11.92
Operating Cost (£/hr)												
Repair , maintenance	1.00	1.00	1.06	1.06	0.68	0.68	1.00	1.00	1.06	1.06	1.00	1.00
Fuel	1.50	1.50	1.00	1.00	1.14	1.14	1.50	1.50	1.00	1.00	1.10	1.10
Tractor hire cost	5.00	5.00	-------	-------	-------	-------	5.00	5.00	-------	-------	--------	--------
Total cost (£/hr)	11.09	10.38	5.90	5.13	6.77	5.79	10.99	10.30	5.65	4.94	16.98	14.02

Plate 6

Sasmo Screw Feed Mechanism

Plate 7

Morbark Drum Chipper

Trial Description

The main objectives of the trial were to:

I. Collect **time study** data to compare outputs between main machine types.

ii. Collect **chip samples** for quality analysis from all machine types in a range of feedstock types.

iii. Examine health and safety issues.

Due to the unpredictable availability of the machinery, the trial was held at 2 sites during September and November 1997. The main site was on Cannock Chase in Staffordshire, with a secondary site on West Dean Estate, West Sussex.

The timber used during the trials fell into several categories listed in Table 3. This consisted mainly of roundwood of various species although some branch wood was used for chip quality analysis. All roundwood processed was measured to give accurate output data during the time studies.

Table 3

Trial Material Specifications

Material	Date Felled	Moisture Content % Wet Based		Material Specifications		
		Sept. Trial	Nov. Trial	Mean Mid Diam (cm)	Mean Length (m)	Mid Diam Range (cm)
Dry oak, Cannock	May 97	37.64	40.75	11	2.24	5 to 25
Green oak, Cannock	August 97	43.12	42.11	14	2.25	5 to 32
Green oak poles, Cannock	August 97	41.5	----------	12	9.26	8 to 18
Pine, Cannock	Winter 96/97	38.04	33.02	14	1.9	10 to 23
Chestnut, West Dean	Summer 96	32.13	----------	8	2.0	4 to 16
Dry Oak, West Dean	Winter 94/95	25.48	----------	14	2.1	5 to 24
Lime, West Dean	Summer 97	48.24	----------	17	2.4	8 to 24
Oak branchwood	August 97	37.05	34.7	-----------	---------	------------

Suppliers of machinery were asked to provide chippers in good condition and correctly set up. All machines were tested on this basis.

Time Studies: The Sasmo, Greenmech, Gandini and Gravely were studied on Forest Enterprise land at Cannock Chase in September and November 1997. The Jenz and Morbark were studied at West Dean Estate, West Sussex, in September 1997.

The Sasmo and Morbark were contractors' machines, the Jenz a private static machine at West Dean, the others were supplied by the manufacturers or agents.

The Sasmo and Gandini were powered by a Unimog tractor unit.

All machines were studied to obtain work output information. The chipping operation was broken down into elements and time studied. This allowed modelling of the data to remove ineffective time and allow a fair comparison between machines.

Timber stacks of known volume were placed at right angles to the forest road. The machinery was positioned at an angle to the produce to minimise the amount of carrying during feeding. A self tipping trailer was positioned next to the chipper to collect the chips. At Cannock, at the end of each study the trailer contents were measured to assess the volume. The trailer was then weighed on a weighbridge *c*. 5 miles away. The contents were re-measured on return to assess any settlement.

At the West Dean study site, chip volumes were measured by taking samples of known volume, weighing and comparing them to a known volume to weight ratio of the feed material. These results are likely to be less accurate.

In general a 2 man system was studied. One man fed and regulated the feed speed, reverse/stop bar or lifting the feed rollers depending on the machine specification and diameter of the material supplied. The second man supplied billets, with the first man assisting with bigger material.

Poles were fed by hand into the Graveley chipper and into the Sasmo by loader and only 1 operator was used. Only 1 man was used by the Jenz.

The operating procedures listed in Arboriculture and Forestry Advisory Group (AFAG) Guide 604 *Wood Chippers* were used during the operation of the machinery. An additional exclusion zone of 25 m was set up to prevent access to the site during operation. Any person within the exclusion area was required to wear ear, eye and head protection.

Chip Samples - Protocol: In order that the quality of chips produced during study work could be described, the following protocol was used to grade chipped material. This protocol was drawn up by Technical Development Branch to assess samples in previous work.

A 20 litre sample of chipped material was collected at random points throughout the chip pile. From this a 2 litre sample was oven dried to determine the moisture content. Another 2 litre sample (Plate 8) was passed through a series of sieves to determine the proportions of the size categories of the comminuted material. The size categories are detailed in Table 4.

Plate 8

Example of 2 litre Chip Sample

Material over 50 mm in length with the grain running longitudinally was classified as a sliver. Material over 50 mm in length with the grain running latitudinally was regarded as a large chip or chunk. These definitions are not standard and other systems do have differing classifications of chips and chunks.

The sieves were agitated until a visual assessment determined that the majority of particles had passed through each category. At the 25 mm size any slivers passing through to a smaller size category were retrieved and physically measured to determine which category they belonged. Each size sample was weighed and converted to a percentage of the total weight.

Chip Samples - Trial: A number of feedstock types and machine settings were used in order to assess the effect of these variables on chip size distribution. The main variables tested were:

I. Feedstock type - Oak poles, shortwood and branchwood.
ii. Moisture content - Dry oak v wet oak.
iii. Product diameter - 5 cm (md) v 15 cm (md)
iv. Feed speed - Fast v slow.
v. Wood basic density - Oak v pine.

Chips from other species were also collected on an opportunistic basis.

All machines processed dry and wet 'Cannock' oak. In addition oak poles were processed by the Sasmo and Gravely chippers. Branchwood was processed by all machines except for the Jenz. In all cases chip samples were obtained for analysis.

To determine whether diameter of the feedstock affected chip size a quantity of small diameter (4 cm to 6 cm) and large diameter (14 cm to 16 cm) material was chipped and a sample of the resultant material collected and sieved. This was undertaken with the Gandini and Greenmech machines.

Table 4

Size Categories (mm)

< 2	2 - 4	4 - 6	6 - 15	15 - 25	25 - 35	35 - 50	50 - 75	75 - 100	100 - 150	150 +

To determine whether feed speed affected chip size a random sample of dry oak was processed at the slowest and fastest safe operational feed speed of the Gandini. Samples from the 2 resultant chip piles were collected and sieved.

Some pine was processed by all the machines at Cannock and samples were collected and sieved.

Trial Results

Outputs and Costs: All machines were time studied, with all fed material measured (m^3 solid) as well as the resultant produce measured (m^3 loose chip). Output was calculated for both solid and chip volumes. The results are summarised in Table 5.

Where possible measured loads were weighed to obtain a solid volume to weight ratio. Moisture content was assessed through oven drying a sample of chips.

The total hourly costs are made up of machine and labour charges. Labour is charged at £8.00/hr and most machine systems assume a 2 man operating team. The exceptions are the Jenz and Sasmo chippers when processing poles. In these systems only 1 man was used.

A cost of £2.00/m^3 solid has been added to the shortwood total costs to account for cross cutting charges. This allows a direct cost comparison with the cost of processing the pole material to be made. No other harvesting or primary processing charges are included. Also no value has been attributed to the timber itself.

Table 5

Output Data and Costs for Machine Types Studied

	Sasmo HP25			Gravely Pro-Chip 395			Greenmech MT 252	Gandini 007 TPS	Morbark EZ Beaver 10		Jenz	
	Material Processed at Cannock								Material Processed at West Dean			
Material	Dry Oak	Green Oak	Oak Poles	Dry Oak	Green Oak	Oak Poles	Dry Oak	Green Oak	Dry Oak W Dean	Chestnut W Dean	Lime W Dean	Chestnut W Dean
Moisture content % wet basis	38%	43%	42%	38%	43%	42%	41%	42%	25%	32%	48%	32%
Throughput (m^3/shr)	5.69	4.79	2.81	2.95	3.12	2.37	3.26	4.27	3.66	5.26	6.36	3.73
Chip output (m^3/shr)	15.41	12.50	--------	7.37	7.08	--------	8.87	11.31	9.11	17.25	19.14	12.08
Volume : weight (m^3 : tonnes)	1:0.96	1:1.05	1:1.05	1:0.96	1:1.06	1:1.06	1:0.87	1:1.01	1:0.91	1:0.86	1:0.83	1:0.86
Solid volume : Chip volume	1: 2.71	1: 2.61	--------	1: 2.5	1: 2.27	--------	1: 2.72	1: 2.65	1:2.49	1:3.28	1:3.01	1:3.24
Solid volume : Chip volume (settled)	1: 2.58	1: 2.48	--------	1: 2.34	1: 1.96	--------	1 : 2.58	1: 2.56	-------------	-----------	-----------	----------
Labour cost	16.00	16.00	8.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	8.00	8.00
Machine cost High usage (£/hr)	10.38	10.38	11.88*	5.13	5.13	5.13	5.79	10.30	4.94	4.94	14.02	14.02
Total cost high usage (£/hr)	26.38	26.38	19.88*	21.13	21.13	21.13	21.79	26.30	20.94	20.94	22.02	22.02
Machine cost Low usage (£/hr)	11.09	11.09	12.59*	5.90	5.90	5.90	6.77	10.99	5.65	5.65	16.98	16.98
Total cost low usage (£/hr)	27.09	27.09	20.59*	21.90	21.90	21.90	22.77	26.99	21.65	21.65	24.98	24.98
Cost of crosscutting poles (£/m^3)	2.00	2.00	-	2.00	2.00	-	2.00	2.00	2.00	2.00	2.00	2.00
Cost: £/m^3 solid high usage**	6.63	7.51	7.07	9.16	8.77	8.91	8.68	8.16	7.72	5.98	5.43	7.85
Cost: £/m^3 solid low usage**	6.76	7.66	7.32	9.42	9.02	9.24	8.98	8.32	7.92	6.12	5.93	8.70

* Costs include additional £1.5/hr for a loader. ** Unit costs exclude charge for timber and harvesting costs.

Chip Quality: Chip samples were sieved using the protocol described earlier. As it is necessary to compare individual samples against a standard, and as there is no current UK standard, the Danish system has been adopted for the purposes of this work. The Danish system is based on 2 grades, fine and coarse. Each grade has the same 5 size categories but the proportions allowed in each category are different for the 2 grades.

The results from the sieving work, and details of size categories for the Danish system, are shown in Table 6.

In the Danish system slivers are described as material over 100 mm in length and large chips or chunks as material between 50 mm and 100 mm. Any following references to chip quality are based on the Danish standard and size category descriptions.

Table 6

Results of Chip Classification Under Danish System

Size Categories	< 2 mm	2-6 mm	6-50 mm	50-100 mm	100 mm +	Grade Achieved	
	Dust	*Undersize*	*Acceptable*	*Chunks*	*Slivers*		
Danish System fine grade	< 10%	< 20%	> 40%	< 25%	< 2%		
Danish System coarse grade	< 7%	< 15%	Any	< 40%	< 15%	Fine	Coarse
Graveley-green oak poles	5.8	23.1	69.7	0.6	0.8	X	X
Graveley-green oak	5.5	11	79.5	3.6	0.4	✓	✓
Graveley-Dry oak	3.8	9.9	68.8	6.8	2.7	X	✓
Graveley-green oak branchwood	0.6	1.2	87.1	8.1	3	X	✓
Graveley-pine	1.7	6.7	88.7	2.9	0	✓	✓
Sasmo-green oak poles	0	0.4	85.4	3.8	10.4	X	✓
Sasmo-green oak	0.5	0.6	94.8	1.1	3	X	✓
Sasmo-Dry Oak	0	0.6	91.8	7.6	0	✓	✓
Sasmo-green oak branchwood	0.5	0.9	68.7	18.1	11.8	X	✓
Sasmo-pine	0.4	0.6	88	8.6	2.4	X	✓
Greenmech-dry oak	5.2	12.6	81.4	0.8	0	✓	✓
Greenmech-dry oak large diameter 14-16 mid	3.3	9.9	85	1.8	0	✓	✓
Greenmech-dry oak small diameter 4-6 mid	0.6	1.7	89.7	2.7	5.3	X	✓
Greenmech-oak branchwood	1.1	2.9	86.9	6.1	3	X	✓
Greenmech-pine	0.4	2.7	90.8	6.1	0	✓	✓
Jenz-lime West Dean	1.6	3.3	94.1	1	0	✓	✓
Jenz-chestnut West Dean	4.8	6.6	88.2	0.4	0	✓	✓
Jenz-green oak Cannock	2.7	4.8	92	0.5	0	✓	✓
Jenz-dry oak Cannock	1	3	93.8	2.2	0	✓	✓
EZ Beaver chestnut West Dean	0.4	0.8	86.9	8.4	3.5	X	✓
EZ Beaver dry oak West Dean	0.8	1.5	80.5	6.3	10.9	X	✓
EZ Beaver green oak Cannock	1.2	3.7	88	4.6	2.5	X	✓
EZ Beaver dry oak Cannock	0.4	0.7	94.4	3.5	1	✓	✓
EZ Beaver oak/thorn branchwood	1.8	1.9	84.1	10.6	1.6	✓	✓
Gandini-dry oak	1.7	10.7	84.5	1.8	1.3	✓	✓
Gandini-dry oak large diameter 14-16 mid	1.1	9.4	88.5	1	0	✓	✓
Gandini-dry oak small diameter 4-6 mid	1.2	10.8	86	1	1	✓	✓
Gandini-dry oak fast feed speed	0.7	3.6	93.5	2.2	0	✓	✓
Gandini-dry oak slow speed	20.1	36.7	40.1	3.1	0	X	X
Gandini-oak branchwood	0.5	9	79	8.4	3.1	X	✓
Gandini-pine	0.8	5.5	87.4	6.3	0	✓	✓

Discussion

Output and Costs: At Cannock the highest output, 5.69 m^3 (solid)/hr and lowest cost, £6.63/m^3 were given by the Sasmo chipping dry oak roundwood. The lowest output of 2.37 m^3/shr was obtained when the Graveley chipped oak poles and the highest cost of £9.16/m^3 when the Graveley chipped oak shortwood.

The highest overall output of 6.3 m^3/shr was achieved by the Jenz chipping lime at West Dean. This also gave the lowest overall cost of £5.43/m^3. These costs assume high utilisation.

Chipping costs may be affected by a number of variables including species, wood basic density, material size, moisture content, machine costs and usage. All the outputs and costs are for roundwood. No output figures are available for branchwood but it is expected that they would be much lower. The total chipping costs for each machine were fairly consistent across the range of material chipped at the Cannock site. The types of material do give different outputs but it is difficult to identify the reasons.

The machines were able to cope with all the material provided. Some jamming occurred when buttresses or bends on the material processed were wider than the throat of the machines. Larger diameter material required the operation of either the 'no stress' systems or manual operation of the reverse feed bar. The Sasmo has no method of controlling the feed speed and the larger diameter shortwood material had to be cut into 2 to 3 shorter lengths to prevent the machine stalling.

Significant cost factors were whether 1 or 2 operators were necessary and if an additional tractor was required to provide power.

The Graveley and Greenmech machines, although capable of comminuting material of 240 mm and 250 mm diameter respectively, produced lower outputs than the larger machines due to their lower power rating. The size of the material supplied required the constant use of the reverse feed or operation of the 'no stress' systems. This indicates that the average size of roundwood should be smaller for the lower powered machines.

The output of the Sasmo when chipping oak shortwood was 70% higher than when cutting oak poles. The cost was also higher as 2 operators were used, compared to 1 for the poles, and the cost of crosscutting was included. The Graveley costs could have been reduced when chipping poles if 1 man and a loader had been used instead of 2 men. However, a 1 man system would require a 'no stress' system to allow the operator to control the poles safely.

At Cannock the solid to chip volume ratios varied from 1: 2.27 to 1: 2.71 m^3 with an average of 1 m^3 solid roundwood to 2.5 m^3 of loose chips. After settling through transportation the bulk of the chips reduces by *c*. 5%. The exception was the green oak shortwood processed by the Graveley which showed a reduction in the bulk volume of 13%. These chips were particularly small with a large amount of fines which could have packed down during transportation to a greater degree than the other samples.

It was hoped that the dry oak would be at a moisture content *c*. 25% wet basis but as there was little difference in moisture content between the green and dry products, there is no firm evidence on the effect of moisture content on output.

Identifying factors which enable an operator to optimise the use and capabilities of a machine is important. The feed stock diameter appears to be significant. The optimum size appears to be that which allows the chipper to operate fully to the point just prior to the need to use the reverse feed or the automatic 'no stress' system. Machine choice should be based on expected feed material diameter.

Chip Quality: In the **Coarse Grade Class** the majority of chips produced during the trial fitted into this category. There were only 2 failures from the 31 samples taken and both failed due to an excess of dust and undersized material. In the case of the Gandini the failure was due to running the feed speed at a very low rate. This was only done as part of the trial to gauge the effect of feed speed on chip size distribution. It in no way reflects the ability of the machine to perform at 'normal' feed speeds. The other failure, on the Gravely, was most likely due to the bluntness of the blades, although this aspect has yet to be fully investigated.

Within the **Fine Grade Class**, 14 of the 31 samples failed to make the grade. The same 2 samples which failed the coarse grade standard also failed the fine grade for the same reason, i.e. undersized material. The other 12 failures were due to an overabundance of chunks and/or slivers. The Sasmo produced the worst results with 4 out of 5 samples failing, although part of the poor performance could be attributed to poor set up.

Slivers: A major problem faced by the woodfuel chip user is large material blocking feed hoppers and screw feeds. Slivers are a particular problem and only a small amount can be tolerated. Within the **Fine Grade Classes** 5 out of the 6 machines produced over 2% slivers in one or more samples. Observations during this trial have identified a number of possible reasons for sliver production.

- **Machine Type:** Machines can only be compared using the same feed material. When processing the smallwood oak from Cannock (high moisture content) no machines produced excessive quantities of slivers. In the oak poles the Sasmo performed poorly, although this could have been caused by the poor set up of the anvil.

- **Moisture content:** Dry oak (*c*. 25% moisture content, wet basis) processed by the EZ Beaver drum chipper produced 10.9% slivers. This may have been due to the brittle nature of the wood. Observation seemed to show that the wood often 'broke and tore' during chipping. Since green oak did not produce similar results, it is likely that the moisture content was the main reason for this poor result. This dry material was not processed by other machines and further investigation is required. This raises the subject of when to chip as, although it is easier to store drier chips, comminution of air dry material may have an adverse effect on chip quality.

- **Machine Set up**: A major cause of slivers appears to be due to the size of the gap between the cutting edge and the anvil. Wear or incorrect setting to the blades and anvil can produce an excessive gap which allows unprocessed material through. In most machines routine maintenance will rectify this. There is a particular problem in the design of the Sasmo where the anvil is an integral part of the machine. Rebuilding by welding and grinding is necessary to rectify the problem. This was evident during the trial when the Sasmo processed green oak poles and produced 10.4% slivers. The majority were strands of fibrous material, some over 1 m in length. The contractor indicated that this was common in green oak. It was not seen on any other material or machine.

- **Branchwood:** Branchwood could be a major source of raw material for chip production. Of the 5 machines which chipped branchwood, 4 produced over 2% slivers. The other, the EZ Beaver was the only machine capable of meeting the standards of the fine grade. The Sasmo produced the highest proportion at slivers 11.8%. The Jenz was not tested at this time but other results would indicate a favourable outcome.

- **End Pieces:** All the machines with feed rollers have a gap between the rollers and the cutting mechanism. The end of the piece being processed often turns sideways after passing through the feed rollers and is processed along the grain producing slivers. This was particularly noticeable in small diameter material.

The Jenz produced no slivers at all from any material and very few chunks, the material in the chunks range was all fibrous and flexible in nature and could not be classified as a chunk. The built in grading plate worked very effectively at recirculating oversized pieces. This recirculation may have resulted in a slightly higher % in the smaller size range, and may have an effect on the output of the machine.

The effect of feed material diameter was tested on 2 machines. The Gandini showed no marked difference in chip size distribution between the 2 sizes. The Greenmech produced more chunks and slivers and less dust and undersize chips in the smaller diameter material. This may be a result of a combination of the unique chipping discs and end pieces of the small diameter material. Further work is necessary to clarify this aspect.

The effect on chip quality that wood basic density had was tested on 4 machines. Three machines produced no slivers, the Sasmo 2.4%. No obvious differences in chip quality were noted from the Cannock oak.

To compare the drum, disc and screwcone chunker type of machine fairly, machines must be of similar size, power and capability.

Chip quality appears less dependant on power than the set up and chipping mechanism. Excluding the static Jenz with its in-built grading system, the EZ Beaver, Gandini and Sasmo are representatives of the 3 types commonly in use. Overall the Gandini disc chipper produced the least slivers and chunks ranging from 0% to 12%, with the Sasmo producing the most at 4% to 30%. The Gandini however produced more dust and undersize chips at 3% to 12%, with the Sasmo producing only 0.4% to 1.4%. From these results the EZ Beaver drum chipper would, at first, appear to be the best compromise. However, due to the importance of the proportions of slivers and chips the Gandini produces far more favourable results.

Health and Safety

During the trial the machinery was operated in accordance with the AFAG Guide 604 *Wood Chippers*. An additional precaution was the erection of a taped exclusion zone around the site for a distance of 25 m, and the placing of warning signs.

Flying Debris: During the trial it was noticed that a number of the larger pieces produced by all the chippers bounced out of the trailer and travelled considerable distances into the adjacent woodland. No measurements of distance were taken during the trial, and further investigation is necessary to determine a safe distance to prevent injury from this material. Chipping towards existing woodland does help to prevent these pieces travelling too far.

Noise Levels: A Rion NA-14 sound level meter was used to obtain an indication of the peak noise levels during feeding. Noise levels were measured at the operator's ear. The levels recorded should only be treated as indicative and are not the result of a full and official assessment (Table 7).

Table 7

Peak Noise Levels dB(A)

	Sasmo HP25	Gravely Pro-Chip 395	Greenmech MT 252	Gandini 007 TPS	Morbark EZ Beaver 10	Jenz
dB(A)	114	119	115	114	119	104

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The peak noise levels recorded during the trial for the Jenz was 104 dB(A) which is similar to the noise levels produced by a chainsaw in operation. The other chippers produced peak levels ranging from 114 dB(A) to 119 dB(A). These readings correspond to the expected levels detailed in AFAG Guide 801 on Noise & Hearing Conservation and require ear protection to be worn.

The Personal Protective Equipment (PPE) in use was suitable for protection during the use of a chainsaw. Although the peak levels of noise were measured, safe levels of exposure are related to the length of time exposed to that level. Consultation with hearing protection manufacturers would suggest that the protection offered by the ear defenders supplied for use with chainsaws is not sufficient to offer complete protection when operating chippers.

Dust and Fine Debris: Chipping produces a considerable amount of very fine dust and chippings. Blustery or strong wind conditions can cause particles to blow over the operators where they could enter the eyes and be inhaled. Positioning of the machine and chipping with the wind can reduce this problem. There is a need to consider the use of goggles and face masks.

Feed Control: The Sasmo has no reverse feed facility and relies on a drop down guard to halt material entering the screw. In long material (e.g. poles) this machine is best operated by feeding using a loader, which can be used to control feed speed.

Machine Safety: On all the machines the blades continue to rotate for a considerable time after they are switched off. The machines should not be left unattended during wind down or operation. No machines have a specific guard to prevent accidental contact with the cutting mechanism. Infeed chute designs however do preclude accidental contact.

Lifting: Manual handling of timber is a consequence of hand feeding chippers. Work should be organised in a way which eliminates injury or controls are put in place to reduce the risk to an acceptable level[1]. Work site layout and the use of appropriate aid tools will be key control aspects. During the study some large pieces of timber were cut into small pieces to prevent operator injury. Team lifting techniques were also employed.

Conclusions

At high usage the most cost effective machine was the Jenz which produced chips from lime at a cost of £5.43/m^3. At low usage the best cost was again achieved by the Jenz processing lime at £5.93/m^3, followed by the Morbark chipping chestnut at a cost of £6.12/m^3. The timber size and the continuous conveyor feed meant the Jenz appeared to be working at its optimum capabilities whilst processing lime. This may account for the lower processing costs. The Morbark chipper was similarly working at its optimum. It is reasonable to assume that chipping lime at the optimum size for the Sasmo should produce higher outputs and similar low costs. This would not however affect the chip quality problems of the Sasmo. Further work with different species is required.

A relationship between moisture content and chip quality has not been identified.

Although the machines tested were capable of chipping their stated maximum diameter, the output from the lower powered machines was drastically reduced towards the higher end of their capabilities. The average size of material to be chipped should be used as a basis for deciding the power requirements to optimise output. A rough guide would be to ensure that the maximum feed size of the machine was larger than the largest piece normally to be chipped so that it was working well within its capacity. The infeed size should only be used to match the maximum diameter of the feed material. However results show that, for the limited sizes of material studied, output increases and cost/m^3 decreases with increased HP even taking into account all machine costs.

If used at the manufacturers' settings and properly maintained, the chippers were all capable of producing chips which fulfill the requirements of the Danish Coarse Grade Classes.

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[1] Forestry Commission (1992). Technical Development Branch, Report 22/92, *Manual Handling of Loads*.

It was possible to achieve the Fine Grade with most of the chippers. Notable exceptions were:

- Sasmo with wet oak poles.
- EZ Beaver in dry oak (moisture content *c*. 25%, wet basis).
- Branchwood with most machines.

The Jenz with its in-built grading and recirculation system produced a good quality chip on all the products tested. Of the standard machines available the Gandini produced the best overall performance when a Fine Grade chip is required, but it fell just outside the requirements on branchwood at 3.1%. The Sasmo produced the lowest overall costs for the range of materials studied.

Health and Safety (PPE): It would appear that the ear defenders used, although sufficient for chainsaw use, may not offer the protection required when operating a chipper. Further investigation is necessary.

The dust and small particles produced by chippers constitute a problem to the operator through lodging in eyes and inhalation. Further work is required to determine the levels of exposure and develop safe working systems to reduce this exposure.

Recommendations

The standard Danish Chip Classification should be used as a basis for quality control.

All machines tested should be capable of producing Coarse Grade Chips.

The choice of a machine to produce Fine Grade Chips should be based on feedstock size and type.

The diameter of material to be chipped should be the basis for deciding the machine size and power required to optimise output, therefore select a machine that would normally be working well within its capacity rather than at its capacity.

The relationship of moisture content to chip quality should be investigated.

The effect of knife sharpness on quality should be investigated.

Work should be undertaken to test in-built grading systems with other feedstock, branchwood in particular. Also to identify other machines with similar systems and the possibility of incorporating such systems into the standard chippers available.

Further work should be undertaken to quantify noise and exposure levels, to determine the hearing protection required when operating chippers.

Further work should be undertaken to quantify the exposure levels to dust. This should identify suitable PPE and identify safe working practices.

Supervisors should carry out Risk Assessments prior to all chipping operations to ensure that PPE and hazards are identified.

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